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CONSERVATION OF WEIGHT AND VOLUME IN SECONDARY SCHOOL STUDENTS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Conservation of Weight and Volume in Secondary School Students submitted by E. D. Hobbs in partial fulfilment of the requirements for the degree of Master of Education.

ABSTRACT

Tests of conservation of weight and volume, of the law of displacement of fluids, and of atomistic schemes were administered to 906 students in grades 7 through 12. Both weight and volume conservation were found to develop during the secondary school years for some subjects. Attainment of conservation of volume was found to be related to sex of subject, particulate matter concepts, and science achievement. Boys performed better than girls on tests of volume conservation and of the law of displacement. Methodology of testing was found to be a significant variable in volume conservation testing. It was concluded that even in senior high school grades (10 through 12), about 10 to 20 per cent of boys and about 30 to 40 per cent of girls may not have established interrelated concepts of weight, volume, and density.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Concepts of physical quantity like weight and volume are basic to physical science. According to Piaget (Piaget & Inhelder, 1968[1]), the development of such concepts occurs in a sequence extending over 11 or 12 years for most subjects. Elkind (1961c) has presented evidence that many adolescents exhibit deficiencies in their concepts of physical quantity. The purpose of this study then is to investigate

(a) the extent to which concepts of weight and volume are developed in secondary school students (grades 7 through 12),

(b) various aspects of the methodology of volume conservation testing, and

(c) whether students' concepts of particulate matter (atomistic schemes) are related to volume conservation.

THEORETICAL BACKGROUND[2]

Framework

Piaget (Piaget, 1965; Piaget & Inhelder, 1968) has drawn a distinction between on the one hand, concepts of weight and volume as properties of a body, and on the other hand, concepts of weight and volume as measurable quantities. The theoretical analysis of his experiments indicates that quantified weight and volume concepts are

not formed automatically upon contact with experience, but are developed in an invariable sequence through interaction between experience and developing thought structures. In the first phase or stage of this sequence, a young child develops a concept of quantity of matter or substance. Then over a period of four or five years on the average, concepts of weight and volume as quantities are developed in turn. The acquisition of a quantity concept is marked by conservation--the behaviour of a subject who recognises that the particular quantity remains invariant during some transformation of a body. For example the acquisition of the conservation of weight by a subject is marked by his assertion that the weight of a piece of clay remains unchanged no matter how its shape is altered.

Definition of terms

Some terms which occur somewhat frequently in the course of the study will be defined here. Other terms which appear may be assumed to have been employed according to dictionary meaning. In some cases special terms are introduced and these will be explained on their first appearance.

1. A standard term in Piagetian theory is grouping of operations. In the present study the operations referred to will be "physical" operations. Both grouping and operations are discussed at length by Flavell (1963). Simply, an operation is an action, but an action which is internalised by a subject in a coherent thought structure. A physical operation is a movement in space and time. The connotations of "operation" applied to a movement in space or time are that the movement

is part of a coordinated system, and that the movement and the system are reversible. To illustrate, the cutting of a piece of clay from a larger stick is no more than a goal-directed, irreversible action. It becomes reversible and part of an operational system (or grouping of operations) when it is coordinated with the simultaneous cutting of a long stick of clay from a slightly longer stick. Such a system works just as well in reverse as in the forward direction. The connotation of "grouping" is that the system of operations conforms to certain mathematical rules (Flavell, 1963, pp. 164-173). In simplest terms, adequate for the purposes of this study, a grouping of operations may be thought of as a <u>thought structure representing some physical transformation of a body in terms of a coordinated system of movements in space and time</u>.

2. By <u>physical quantity</u> is meant specifically in this study the concepts of weight and volume. In general the term would apply to any measurable physical entity (e.g. density, momentum, etc.). Weight and volume as <u>properties</u> of a body should be distinguished from weight and volume as <u>quantities</u>. For example, a body has the property of weight or of being heavy, but the concept of weight is quantified only when number is applied to it.

3. <u>Conservation</u> is an attendant symptom of achievement of quantification of a property. Conservation with reference to a given physical quantity may be defined as the behaviour of a subject who recognises that the quantity remains invariant in some transformation of the body (e.g. a change in its shape).

4. <u>Physical volume</u> or <u>occupied volume</u> is to be distinguished

from interior volume. Whereas interior volume refers to the quantity of material contained in a body, physical volume refers to the volume occupied by the body in relation to exterior three-dimensional space.

5. A scheme is a ready-made thought structure which can be applied in a variety of situations by the subject. An atomistic scheme is a scheme by which transformations of a body are represented by transformations of elements (particles, grains, drops, atoms etc.) which form that body. An atomistic scheme of compression or dilatation is an atomistic scheme representing changes in volume of a body. Usually in this study reference is made to the atomistic scheme of compression and dilatation which represents the volume changes as decreases or increases in distances between particles of invariant weight and volume.

OUTLINE OF THE EXPERIMENT

Tests and Procedure

The design of tests and procedure of administration are described in Chapter III. Briefly, 906 students in grades 7 through 12 in a single school authority were tested in groups for (a) conservation of weight, (b) conservation of volume, and (c) understanding of the displacement law, by means of oral questions with demonstrations; and for (d) atomistic schemes of compression and dilatation by means of a short written test. Weight conservation items included both simple and complex transformations. Volume conservation items included both verbal and displacement questions, and both rigid-body and plastic-body transformations. In addition, for most of the grade 9 subjects in the

sample, results on previously administered standardised tests of science achievement and scholastic aptitude were obtained.

Assumptions

Generally, the present study assumes Piaget's theoretical position. Thus it is assumed that there is a uniformity of development of thought structures, and that the sequence and the structure can be examined by "tapping" behaviour at various points in the sequence. More specific theoretical and procedural assumptions include the following:

1. Although volume conservation and the law of displacement are related concepts, they are nonetheless distinct.

2. There is no great variation in curriculum experiences of the subjects in the sample.

3. The grade 9 section of the sample (for which results of standardised tests were available) is representative of the sample as a whole.

4. In the testing, subjects understand the questions and do not look for extraneous factors or "tricks" when the question appears to be very easy.[3]

5. Subject-experimenter interactions and other reactive effects of the testing procedure are negligible.

Delimitations

Delimitations imposed by time-cost considerations include the following

1. The study in cross-sectional rather than longitudinal.

2. Subjects were tested in groups rather than individually.

3. The test length was limited to 40 minutes to coincide with a normal school period.

4. Classification of subjects was limited to the categories conserver and nonconserver. No attempt was made to isolate transitional cases. In addition, more or less arbitrary delimitations imposed on the study include the following:

5. Only secondary school (grades 7 through 12) students were tested.

6. Physical quantity concepts tested are restricted to those of weight and volume.

CONSERVATION OF WEIGHT

It appears now well established that weight is conserved by the age of 10 years on the average. It may be asked however whether <u>all</u> subjects in secondary school grades conserve weight, or whether some students develop this ability during the secondary school grades. Further, the results of some experiments (King, 1961; Lovell & Ogilvie, 1961a) indicate that subjects who conserve weight in simple transformations, like deformation of clay, may not conserve weight in more complex transformations, like change of state of water. It may be asked therefore whether nonconservation in complex transformations like change of state can be demonstrated to exist in secondary school students, and if it does exist, whether it can be explained in Piagetian terms.

Accordingly, the following hypotheses are proposed:

1.1 There are students in secondary school grades who may be classed as nonconservers of weight in simple transformations like change of shape.

1.2 There are students in secondary school grades who may be classed as conservers of weight in simple transformations but who do not conserve weight in complex transformations like change of state.

1.3 The incidence of nonconservation of weight in both simple and complex transformations decreases with grade.

VOLUME CONSERVATION

Although according to Piaget (Piaget & Inhelder, 1968) most subjects[4] conserve volume by the age of 11 or 12, there is evidence (Elkind, 1961c; Uzigiris, 1964) that up to 30 per cent of grade 12 students may not conserve volume. Elkind's results also indicate that greater proportions of males than females conserve volume in the junior and senior high school. Uzigiris (1964) notes that her results for proportions of conservers are at variance with results obtained by Piaget (1968) and by Lovell and Ogilvie (1961), but in agreement with those of Elkind (1961c). Uzigiris suggests that the kind of question asked in a volume conservation experiment may affect the results--higher proportions of conservers being obtained when the question is asked in terms of displacement levels caused by immersion of bodies in water, than when the question is asked in terms of space or room occupied by bodies. Briefly, conservation of volume is tested by showing the subject

two identical bodies, transforming one of them (by changing its shape or dividing it etc.), then asking the subject a question in order to determine whether he understands that the volume of the transformed body is still the same as the volume of the untransformed body.[5] Two ways of asking the question are (a) "Do the two bodies take up the same amount of space or room?"--the verbal question, and (b) "If the two bodies are immersed in identical containers of water, will each cause the water level to rise the same amount?"--the displacement question. In effect, the suggestion of Uzigiris is that a verbal question is more difficult than a displacement question, possibly because it tests the volume concepts at a more abstract level. It is proposed here however that a subject may correctly predict the level which results from immersion of a transformed body without actually conserving volume if he thinks that the weight of the immersed body determines the displacement level. By conserving weight, such a subject may appear to be conserving volume. It may be asked in this connection what links exist between the conservation of volume and understanding of the displacement law (the recognition that an object immersed in fluid displaces its own volume of fluid), at least when water is the displaced fluid.

Another methodological difference in volume conservation testing concerns the type of transformation used. Two types of transformation may be discerned: (a) a "rigid-body" transformation, which involves no more than division of a body or rearrangement of separate sections (e.g. blocks), and (b) a "plastic-body" transformation, which involves the change in shape of a plastic body. The descriptions refer to the transformations, not to the objects being transformed, so that a rigid-

body transformation may be performed on a plastic material--e.g. a piece of modeling clay may be cut into a number of pieces. Another example of a rigid-body transformation is the rearrangement of a stack of cubes to form a stack with different dimensions. An example of a plastic-body transformation is the squeezing of a ball of modeling clay into a sausage shape. Intuitively it seems that the squeezing out of clay may appear to involve compression or dilatation and hence be a more difficult volume conservation problem than restacking of cubes.

Accordingly, the following hypotheses are proposed with reference to the displacement law:

2.1 There are significant proportions of students in secondary school grades who do not recognize that a body immersed in water displaces its own volume of water (i.e. do not understand the displacement law).[6]

2.2 Higher proportions of girls than boys do not understand the displacement law.

The following hypotheses are proposed with reference to the conservation of volume:

3.1 There are significantly large proportions of students in secondary school grades who may be classed as nonconservers of volume.

3.2 Higher proportions of boys than girls conserve volume.

3.3 The proportion of nonconservers of volume in rigid-body transformations (involving only simple sectioning or relative displacement of separate parts) is lower than the proportion of nonconservers of volume in plastic-body

transformations.

3.4 Higher proportion of nonconservers of volume are found in tests involving verbal questions only, than are found in tests involving displacement of water only, because of subjects who believe weight causes displacement and thereby conserve weight, not volume, in the displacement question.

MENTAL ABILITY AND SCIENCE ACHIEVEMENT

Elkind (1961c), Goodnow and Bethon (1966) and Hermeier (1967) have demonstrated links between conservation ability and mental ability. In the present experiment sex differences will be sought in relation to conservation ability. Therefore it may be asked whether any sex difference which might be found is not the result of a difference in mental ability between the sexes in the sample being tested. Accordingly the following hypothesis is proposed:

4.1 No sex difference in mental ability exists in the sample tested for volume conservation.

In addition there is evidence (Leon, 1972) that science achievement is correlated with conservation ability. It may be asked more specifically whether moderate to high science achievement is incompatible with lack of weight conservation. Accordingly the following hypothesis is proposed:

4.2 A tendency exists for subjects whose scores are below the mean in a test of weight conservation to have scores below the mean in a test of science achievement.

ATOMISTIC SCHEMES

According to Piaget (Piaget & Inhelder, 1968), achievement of conservation of volume is accompanied by the spontaneous development of particulate representations or "atomistic schemes" of compression and dilatation. By means of such schemes, the subject reduces volume changes to systems of increases or decreases in the distances between particles of invariant weight and volume. The Piagetian notion of atomistic schemes will be discussed extensively in Chapter II. It may be asked whether a link can be established statistically between possession of these atomistic schemes and volume conservation. Accordingly the following hypothesis is proposed:

5.1 Attainment of volume conservation is significantly correlated with attainment of atomistic schemes of compression and dilatation.

SUMMARY

In a preliminary discussion of the background to the problem, the following points have been made:

1. Experimental evidence and Piagetian theory indicate that some students in secondary school grades may not have developed quantified concepts of weight or volume.

2. Experimental evidence indicates that more girls than boys in secondary school grades may not have developed adequate concepts of

volume.

3. Piagetian theory and experimental evidence indicate that atomistic schemes of compression and dilatation may develop spontaneously along with the concept of volume.

4. Discrepancies among the results of various volume conservations experiments indicate that the method of testing employed may affect the levels of conservation found in a given experiment. In particular, two variables associated with the testing method can be separated: (a) the type of transformation used, and (b) the type of question asked.

Accordingly a number of specific hypotheses were advanced to test

(a) whether for some subjects concepts of weight and volume develop during the secondary school grades,

(b) the effects on weight and volume conservation of varying the methodology of testing, including the transformation and the type of question asked,

(c) differences according to sex in acquisition of weight and volume conservation,

(d) relationships between volume conservation and subjects' notions of displacement of liquids,

(e) relationships between volume conservation and subjects' particulate or atomistic schemes of compression and dilatation.

(f) relationships between weight conservation and science achievement.

OUTLINE OF THE REPORT

In Chapter II, the theoretical framework of the study will be discussed in depth, and research related to the present study will be reviewed. In Chapter III the design of the experiment will be detailed and discussed. The results of the experiment will be reported in Chapter IV and discussed in Chapter V. Chapter VI will conclude the report with a discussion of implications of the study for (a) science curriculum in secondary school grades, (b) methodology of volume conservation testing, and (c) further research.

FOOTNOTES -- CHAPTER I

1. Years of publication in citations refer to the edition used in preparation of the present study. These do not necessarily correspond to the years of original publication, especially when the reference is to an English translation of a Piagetian work. Hence any order or sequence implied by the years in parentheses is certainly not the order of first appearance of Piaget's works.
2. The theoretical background is discussed in depth in Chapter II.
3. Certain precautions against this possibility were taken in the administration of the tests. These precautions are described in Chapter III.
4. That is, more than 75 per cent.
5. The methodology of volume conservation testing is examined in detail in Chapter II.
6. Operational criteria for understanding of the displacement law will be defined in Chapter IV (p. 92).

CHAPTER II

BACKGROUND TO THE STUDY

The review of the literature which follows will commence with an outline and critique of the seminal work on physical quantity concepts by Piaget and Inhelder (1968). Subsequent development of Piaget's position with respect to the conservation of volume will be examined. A discussion of the methodology of conservation testing in general and of volume conservation testing in particular will follow. Finally, in the light of the preceding theoretical discussions, replications, refinements, and related studies will be reviewed.

PIAGET AND INHELDER

Le Développement des Quantités

The first edition of *Le développement des quantités physiques chez l'enfant* (Piaget & Inhelder, 1968), published in 1941 under a slightly different title,[1] was a follow-up work to *The child's conception of number* (Piaget, 1952). Physical quantity is defined by Piaget as the generalisation and application of "numerical" quantity to notions of matter, weight, and volume. The subject becomes aware of these notions through his own actions. He does not encounter them as single enumerable items to which number can immediately be applied. The central problem in *Le développement des quantités* then is how the child achieves the application of numerical concepts to the physical properties

of having substance, having weight, and occupying space (substance, weight, and volume). This achievement results in <u>quantified</u> substance, weight, or volume concepts. According to Piaget, the acquisition of <u>conservation</u>, i.e. the behaviour displayed by a subject when he is aware that a given property must remain invariant in some transformation of a body, is both a condition and a result of the quantification of that property.

<u>Sequence of Development of Physical Quantity</u>

In an extended series of experiments, Piaget and Inhelder (1968) were able to discern four stages of development in the child's acquisition of physical quantity. In the first of these experiments, 180 subjects aged from four to ten years were shown two identical balls of modeling clay, one of which was then transformed by changing its shape or breaking it into smaller pieces. Subjects were asked whether the amount of clay, the weight of clay as measured on a balance, or the room occupied in water by the clay were the same for the transformed ball as for the untransformed ball. In the first stage (Stage I), before 7 or 8 years on the average, the subject does not conserve substance (quantity of matter), nor weight, nor volume. Apparently he conceives of no aspect of the object which remains unchanged in the transformations. In the second stage (Stage II), from 8 to 10 years on the average, the subject conserves substance, but believes that both weight and volume vary in the transformations. In the third stage (Stage III), from 10 to 11-12 years on the average, substance and weight are conserved, but not volume. In the fourth stage (Stage IV), the subject is convinced

that throughout the transformations the amount of clay, its weight, and its volume remain unchanged. In each of the last three stages a transitional phase or sub-stage was discerned (Sub-stages IIA, IIIA, IVA) in which the subject conserves in some transformations but not in others. The second sub-stage (IIB, IIIB, IVB) is marked by <u>necessary</u> conservation, i.e. conservation affirmed in all situations as a logical necessity.

Piaget claims that this four-stage sequence of development represents an invariable order. Apparently no subjects were found who were able to conserve volume but not weight, or weight but not substance. Each conservation in turn is thought to be achieved through a grouping of concrete operations. Physical quantity involves "physical" or "infralogical" operations whereas numerical quantity involves "logical" operations.[2] Grouping of the physical operations is effectively a reduction of the transformations to systems of sectionings and displacements of parts of the object being transformed. Piaget claims that an exactly similar grouping of operations is required for each physical quantity in turn, even though years may intervene between their successive achievement. These seemingly paradoxical lags or <u>décalages</u> are indicative of the nature of concrete operational systems. Such systems are initially specific to the content for which they are structured, and have to be reconstructed anew for each new empirical content (cf. Piaget & Inhelder, 1958, pp. 281-282). The invariable order of achievement of these groupings for substance, weight, and volume is explained both as an order of difficulty and as a hierarchy of prerequisites. Invariant substance is initially only an intuitive notion

that something is conserved. Invariant weight is more difficult to achieve because it is known only through actions of the subject, and it remains tied to misleading perceptual associations for some time. Invariance of weight presupposes a more basic entity to which weight can be ascribed. Invariant volume requires the solution of some relatively complex problems as will be seen below, and invariance of volume presupposes a fixed consistency of matter which to the child implies conservation of weight (pp. 318-319). In later works (Piaget, Inhelder & Szeminska, 1960; Piaget & Inhelder, 1958), Piaget insists that volume conservation requires formal operational concepts (see below, pp. 23-25).

Atomism. In *Le développement des quantités*, attention was not confined to deformations of a ball of clay--in a second experiment more than 100 children aged from 4 to 12 years (p. 84) were shown sugar lumps being placed in water and subsequently dissolving. They were asked to explain what was happening and to say whether the weight would remain the same and whether the increased water level would be maintained as the sugar dissolved. A sequence of development was found to exist for this transformation which was parallel with the sequence for the simpler deformation of clay. If groupings of physical operations of sectionings and displacements are required for quantity conservation, then the elements being sectioned or displaced in the case of dissolution of sugar would have to be invisible individual elements. That is to say, conservation of physical quantity would require a particulate concept of matter--a concept of "atomism". Piaget claims to have detected a progressive construction of atomism in an ever-increasing number of

subjects from stage to stage in the developmental sequence of physical quantity (p. 84). Conservation of volume, Piaget maintains, is achieved only with the construction of atomistic schemes of compression and dilatation, in which volume changes are envisaged as decreases or increases in distance between equivalent particles of invariant weight and volume (p. 66).

In the dissolution of sugar experiment, Stage I (nonconserving) subjects were found to believe that the sugar lost all existence as it dissolved. Stage II (substance conserving) subjects were found to oscillate between ideas of metamorphosis (sugar turns to water) and nascent atomistic constructions (the sugar splits up into weightless invisible particles which occupy no space). Stage III (substance and weight conserving) subjects were found to display atomistic schemes based on particles (grains, packets, powder) which had invariant weight, but which occupied no room in the water. Stage IV (volume, weight, and substance conserving) subjects were found to display atomistic schemes of compression and dilatation based on particles of invariant weight and volume. A given stage of conservation was always accompanied by appropriate atomistic schemes, which apparently were spontaneously constructed by the subjects as they were confronted with the experimental facts of the situation (that the liquid level and the weight remain unchanged as the sugar dissolves).

Further evidence for the construction of atomistic schemes in parallel with achievement of conservation was obtained in a third experiment by questioning subjects about the popping of corn and expansion of mercury in a thermometer. Subjects failing to conserve

volume (Stage III) were found to envisage the expansion as swelling of the constituent particles. Volume conservers again were found to have atomistic schemes of compression and dilatation involving particles of invariant volume.

According to Piaget, the atomistic schemes of compression and dilatation are not merely collections of representational imagery, but are inseparably related to the grouping of operations necessary for conservation of volume, and result from that grouping (p. 156). The role of imagination is subservient to the requirements of the construction of the operational system (p. 139). To illustrate, the earliest representational schemes for the dissolution of sugar consist of irreversible evanescence of sugar grains. The operational requirements for Stage IV conservation are provided by representations involving displacements of particles of invariant weight and volume. These are the very representations found in Stage IV subjects.

Density. In a fourth experiment, subjects were required to explain why a small pebble was heavier than a larger piece of cork, or why two stones of the same apparent volume (one pumice) had different weights. Again four stages were discerned, parallel with those already discussed. In the first two stages, differences in density are explained by irrational references to some inherent nature or to an imagined history of the objects. In Stage III, the differences are explained in terms of a kind of "fullness" of matter, while in Stage IV, the differences are explained in terms of compactness of separate particles and density is seen to result from an inverse-proportional relationship between apparent volume and the "corpuscular quantity of

matter" (pp. 178-179). The concept of density is thus not achieved until after a concept of physical volume.

Form and Content. The remaining experiments in Le développement des quantités were designed to help solve the problem of the relationship between thought and experience, or in other words, between the form of the operational groupings or groups and their content. Subjects were asked to seriate weights or volumes, and to perform other logical operations like transitivity etc. upon weights and volumes. It was concluded that the ability to perform such operations on a given physical quantity is achieved at the same time as conservation of that quantity but not before, in spite of the fact that the child can perform such operations on numerical quantity at much lower ages. Then in the light of the experimental findings, Piaget proceeds to make the point, in a lengthy theoretical discussion, that form and content, or thought structures and experience, do not exist independently from one another but are completely interdependent. The four factors he believes to be involved in the elaboration of thought structures are maturation, experience, social interaction, and equilibration between these three.

Critique. It has become platitudinous to criticise the faults of method and reporting associated with the work of Piaget, but there are some very unfortunate omissions in Le développement des quantités which create unnecessary difficulties for the reader. For only two of the investigations are numbers of subjects reported. In only one of the investigations is a tabulation of the results given. No descriptive information is given about the subjects other than their ages, and there is no indication of whether or not the same subjects participated

the identity of the two configurations. Mere identity, otherwise called "pseudo conservation" (Piaget, 1967) can occur when one essential element of the conservation problem is missing--immediate perceptual difference in the two configurations. When there is no comparison initial configuration, the subject has to imagine what the initial configuration was. As Elkind (1967) puts it, through "memory falsification" the subject may arrive at pseudo conservation. Similarly, the final configuration must also be present in the final comparison. Piaget (Piaget, 1967; Piaget & Inhelder, 1971) has demonstrated the existence in subjects of "false anticipatory images." Thus if a subject who recognises identity of a body in a transformation has to imagine either the initial or final configuration, his memory of the initial configuration or his anticipatory image of the final configuration will be such that the observed and imagined configurations will be perceptually identical. In short, in the absence of either the comparison initial configuration or the final configuration, what purports to test conservation may merely test identity, an acquisition prior to conservation. The proportion of conservers found in such a test would thus be an overestimate. Therefore the first essential element in a conservation test is

A. <u>presence of both the final configuration and a comparison initial configuration for comparison by the subject</u>.

Between the final and initial configurations is the transformation (step 2). There is evidence that actual demonstration of the transformation may not be essential. Phillips (1970) tested two groups of subjects for volume conservation. The transformations were

actually demonstrated to subjects in one group and were merely described with the aid of pictures to subjects in the other group. No difference in the proportions of conservers was found between the two groups. Nonetheless, whether it is described or demonstrated the transformation is an essential element of the conservation test. Without the transformation, the test is not of conservation but of estimation of the physical quantity. According to Elkind (1966), estimation is a more difficult task than conservation. In fact, the logical certainty characteristic of necessary conservation could not be possible for an estimation of whether two give bodies were equal in weight or volume. Therefore the second essential element of a conservation test is

B. demonstration or at least description of the transformation.

An important related question is what difference the actual transformation makes, i.e. are subjects more likely to conserve in one transformation than in another? Piaget obviously saw that some subjects conserve in some transformations and not in others, since his tests always include a variety of transformations. A subject who conserves only for some transformations is classed as a transitional case. The weight conservation tests used by Piaget and Inhelder (1968) involve three different transformations of clay--(a) rolling a ball into a sausage, (b) flattening a ball into a pancake, and (c) breaking a ball into several pieces. If a test uses only one transformation, then there is no easy way to distinguish necessary conservers from transitional conservers. Therefore the third essential element of a conservation test is

C. use of a variety of transformations.

Some of the experiments which will be reviewed use a volume conservation test with a different type of transformation than deformation of clay. This type of test is based on the volume conservation experiment described in The child's conception of geometry (Piaget, Inhelder, & Szeminska, 1960). In this experiment, the transformations consist of rearrangements of a fixed number of cubes to form rectangular solids with different dimensions. In the preceding chapter (pp. 8-9) this type of transformation was labelled "rigid-body" as compared to "plastic-body" for deformation of clay. It was hypothesised there that fewer subjects might conserve in plastic-body transformations than in rigid-body transformations. Thus an important theoretical question is what determines the relative difficulty of different transformations for the transitional conserver.

In an experiment designed to test the "situational generality" of conservation, Uzigiris (1964) tested substance, weight, and volume conservation in a series of different "situations." Three different kinds of transformations were used with each of four different materials (making 12 combinations). The four materials were plasticene, metal cubes, wire coils, and plastic wire. Significant differences were found among scores for the four different materials. Now if the deformations of the plasticene and the rearrangements of the metal cubes are taken as examples of plastic-body transformations and rigid-body transformations, respectively, then a comparison of the proportions of conservers for these two materials actually represents a comparison of the two types of transformation. For 12-year-old subjects (N = 20), the proportions of volume conservers were 20 per cent for

plasticene, and 30 per cent for metal cubes. For a given material, the effects of different transformations are indicated by the proportions of subjects who conserve for either one or two of the three transformations. For conservation of volume, the proportion of such subjects was 5 per cent in all four materials for the 12-year-old subjects.

Uzigiris' transformations were, however, only marginally different from each other, and were arbitrarily selected rather than based on some theoretical position. Lovell and Ogilvie (1961a) found in the course of a weight conservation experiment that changes in "hardness" were very perceptually misleading. For example, 38 per cent of 50 eleven-year-old subjects thought that butter would weigh more if it were cooled and hardened. King (1961) found that 64 per cent of 103 eleven-year-old subjects thought that ice would weigh more than the corresponding amount of water. Vinh-Bang and Inhelder (Inhelder, 1968) found higher proportions of weight and volume conservers at a given age level for deformation of clay than for dissolution of sugar. For example, the proportions of 11-year-old subjects classed as conservers of weight were 96 per cent ($\underline{N}$ = 25) for deformation of clay, and 78 per cent ($\underline{N}$ = 27) for dissolution of sugar. Some transformations therefore (hardening of butter, freezing of water, dissolution of sugar) seem to be more "complex" than deformations of clay or restacking of blocks. Explanations for this complexity will be forwarded in Chapter V of the present study in relation to the data collected.

The need for the presence of both configurations in the comparison, the need for a variety of transformations, and the effects

in different investigations. For example, it is claimed that the results showed that atomistic schemes developed in complete parallel with the quantity concepts. Presumably, to make such an inference it would be necessary to test for conservation and for atomistic schemes in the same subject. There is no indication whether or not the subjects in the popcorn and thermometer tests for atomistic schemes of compression and dilatation were tested for conservation of volume in the deformation of clay experiments. Neither is there any indication whether the various stages in the dissolution of sugar or in the popcorn and thermometer tests were achieved at the same time as they were achieved for deformation of clay tests.

In general the reporting of experimental findings is limited to that of selected protocols of subjects who are readily classifiable in one of the stages or sub-stages. These protocols are quoted in illustration only, and the reader is left to guess at their typicalness. On the other hand, the actual method of testing is described in detail in every case, while even more detailed descriptions of the procedures are given by Inhelder in _The diagnosis of reasoning in the mentally retarded_ (1968, pp. 343-352).

The two most significant aspects of _Le développement des quantités_ are (a) the demonstration of the substance-weight-volume _décalage_ (i.e. the delay between the first grouping of operations for substance and its subsequent application to weight and volume), and (b) the analysis of the relationship between thought structures and experience. These two aspects themselves can be taken to represent content and form, and are closely interrelated. What Piaget has shown

is how the acquisition of physical quantity follows a lengthy, ordered, invariable sequence of development, characterised by décalages (the reconstruction, for successive empirical content, of thought structures which have the same form). Further, he has demonstrated the existence in the sequence of (a) synchronisms, e.g. the simultaneous appearance in subjects of conservation of weight and the ability to seriate weights, and (b) uniformities, e.g. the exact parallel between the logical and physical operations, or the identical nature of conservation once achieved whether for substance, weight, or volume. It is the examination of these four: invariable sequence, décalages, synchronisms, and uniformities, which forms the experimental and theoretical basis of Piaget's theory of cognitive development.

Developments in the Problems of the Volume Concept

In works subsequent to Le développement des quantités Piaget appears to have modified his ideas about the concept of volume. The impression conveyed in the initial work was that volume conservation and the quantification of volume are achievements of concrete-operational thought. The main obstacles to the conservation of volume were seen to be the necessity to disentangle the volume-weight-density relations and to construct an atomistic scheme of compression and dilatation. In a later work (Piaget et al., 1960) Piaget claims that volume can be conserved only when the subject succeeds in establishing the appropriate relations between the volume of a body and the boundary surfaces, which requires operations "which are known to be impossible before the level of formal thinking" (p. 371). In addition the problem of volume was

shown to be complicated by the existence in younger children (about 9 years) of conservation of "interior" volume but not of "occupied" or "physical" volume as studied in Le développement des quantités. Interior volume refers to the quantity of matter contained within the boundary surfaces, while occupied volume refers to amount of space occupied by the body. In yet another work (Piaget & Inhelder, 1958) Piaget states categorically that "the conservation of volume is not worked out completely before the beginning of the formal level . . . . Without a doubt the reason for this is that, in contrast to simple forms of conservation, which the subject masters by simple additions and compensations, the conservation of volume through change of form presupposes the ability to handle proportions" (p. 36). Are these respective positions conflicting or complementary? Certainly they are not integrated. The later statements about the roles of formal operations, of relationships between boundary surfaces and enclosed volume, and of proportionality schemes bring into question the earlier statements about the role of atomistic schemes as the representational forms of groupings of concrete operations.

Whether the atomistic schemes are instrumental in the grouping of operations, or whether they are after-the-fact manifestations of the achievement of the grouping is not made immediately clear in Le développement des quantités. Piaget maintains that the imagery or symbolic representation is subservient to the requirements of the construction of the operational system (p. 139). He also maintains that only the one atomistic scheme of compression and dilatation leads to conservation (pp. 66-67). Again, the achievement of the correct

atomistic scheme of compression and dilatation is seen to be both the manifestation of the process (grouping of operations) which leads the subject to conservation, and the vehicle by which conservation can be explained (p. 159). A reasonable interpretation seems to be that the atomistic scheme is the final expression in concrete operational form of the solution which cannot be reached without the use of formal operational schemes. That is, although volume conservation is ultimately achieved as a grouping of concrete operations, certain prior problems have to be solved at a formal operational level.

Apparently there are at least four necessary conditions for attainment of volume conservation: (a) conservation of weight, (b) establishment of relations among the boundary surfaces, the enclosed volume, and surrounding three-dimensional space, (c) proportionality schemes, and (d) atomistic schemes of compression and dilatation.[4]

Flavell

A clear and succinct summary of the first edition of _Le développement des quantités_ is given by Flavell (1963, pp. 300-303). Flavell interprets the role of the atomistic scheme of compression and dilatation as a requirement for a "genuine grasp of the concept of volume and its relation to weight." An omission in Flavell's account is that it fails to place due emphasis on what is the major theme of the book, namely the interaction between thought structures and experience. Unfortunately, the descriptions he gives of the volume conservation experiments are seriously deficient as to detail. As he describes the

procedure, "A glass container with water in it is used as the common measure. The experimenter shows that each ball of clay, when placed in the container, causes the water level to rise to the same height. He then alters one of the balls and asks if it will still make the water rise to that same height." In fact, the Piagetian procedure[5] involves much more than this. First of all, the experimenter is careful to establish for the subject that it is not the weight which causes the displacement, stipulating that the rise is caused by the room occupied by the immersed object (Piaget & Inhelder, 1968, p. 282). Moreover, the question is always posed by asking if the transformed object <u>occupies the same room in the water</u> as the untransformed object, as well as by asking if the water level rise will be the same (pp. 60-61). In the introduction to the second edition (Piaget & Inhelder, 1968, p. xviii) Piaget describes an additional control--that of substituting a metal ball of the same dimensions for the untransformed clay ball before asking the conservation questions. It is not clear whether this procedure was used in the original experiments, or just in the subsequent standardisation experiments described in that introduction. Obviously a question asked in the manner described by Flavell can be answered correctly by subjects who conserve only weight if they believe that the weight of the immersed object determines the rise in level.

CONSERVATION TESTING METHODOLOGY

Before proceding to review physical quantity research based on

the pioneer work of Piaget and Inhelder, conservation testing itself will be analysed. The analysis will provide a basis on which to examine both procedure and results in the experiments which will be reviewed. First the essential elements of a conservation test will be determined and their importance discussed. A brief discussion of criteria of conservation will follow, and finally conclusions will be reached about interpretation of quantity conservation experiments.

Elements of Conservation Testing

There are three essential steps in an orthodox Piagetian conservation task. These steps will now be outlined and then analysed for their essential elements. The steps are:

1. Two identical bodies are demonstrated to the subject in some initial configuration--e.g. two balls of clay.

2. One of the bodies is transformed as the subject observes--e.g. one of the balls is rolled out into a sausage.

3. The subject is required to compare the transformed body with the untransformed body in terms of some operational measure of the quantity being tested--e.g. the subject is asked if the ball and sausage will weigh the same on a balance, or will raise the levels of water in two identical glasses to the same height.

Elkind (1966) has shown the importance of starting in step 1 with two bodies, one of which remains unchanged throughout. Should one body only be demonstrated and then transformed, a subject may appear to conserve merely by recognising that it is the same body after the transformation as it was before. In other words the subject recognises

the identity of the two configurations. Mere identity, otherwise called "pseudo conservation" (Piaget, 1967) can occur when one essential element of the conservation problem is missing--immediate perceptual difference in the two configurations. When there is no comparison initial configuration, the subject has to imagine what the initial configuration was. As Elkind (1967) puts it, through "memory falsification" the subject may arrive at pseudo conservation. Similarly, the final configuration must also be present in the final comparison. Piaget (Piaget, 1967; Piaget & Inhelder, 1971) has demonstrated the existence in subjects of "false anticipatory images." Thus if a subject who recognises identity of a body in a transformation has to imagine either the initial or final configuration, his memory of the initial configuration or his anticipatory image of the final configuration will be such that the observed and imagined configurations will be perceptually identical. In short, in the absence of either the comparison initial configuration or the final configuration, what purports to test conservation may merely test identity, an acquisition prior to conservation. The proportion of conservers found in such a test would thus be an overestimate. Therefore the first essential element in a conservation test is

A. presence of both the final configuration and a comparison initial configuration for comparison by the subject.

Between the final and initial configurations is the transformation (step 2). There is evidence that actual demonstration of the transformation may not be essential. Phillips (1970) tested two groups of subjects for volume conservation. The transformations were

actually demonstrated to subjects in one group and were merely described with the aid of pictures to subjects in the other group. No difference in the proportions of conservers was found between the two groups. Nonetheless, whether it is described or demonstrated the transformation is an essential element of the conservation test. Without the transformation, the test is not of conservation but of estimation of the physical quantity. According to Elkind (1966), estimation is a more difficult task than conservation. In fact, the logical certainty characteristic of necessary conservation could not be possible for an estimation of whether two give bodies were equal in weight or volume. Therefore the second essential element of a conservation test is

B. <u>demonstration or at least description of the transformation</u>.

An important related question is what difference the actual transformation makes, i.e. are subjects more likely to conserve in one transformation than in another? Piaget obviously saw that some subjects conserve in some transformations and not in others, since his tests always include a variety of transformations. A subject who conserves only for some transformations is classed as a transitional case. The weight conservation tests used by Piaget and Inhelder (1968) involve three different transformations of clay--(a) rolling a ball into a sausage, (b) flattening a ball into a pancake, and (c) breaking a ball into several pieces. If a test uses only one transformation, then there is no easy way to distinguish necessary conservers from transitional conservers. Therefore the third essential element of a conservation test is

C. <u>use of a variety of transformations</u>.

Some of the experiments which will be reviewed use a volume conservation test with a different type of transformation than deformation of clay. This type of test is based on the volume conservation experiment described in The child's conception of geometry (Piaget, Inhelder, & Szeminska, 1960). In this experiment, the transformations consist of rearrangements of a fixed number of cubes to form rectangular solids with different dimensions. In the preceding chapter (pp. 8-9) this type of transformation was labelled "rigid-body" as compared to "plastic-body" for deformation of clay. It was hypothesised there that fewer subjects might conserve in plastic-body transformations than in rigid-body transformations. Thus an important theoretical question is what determines the relative difficulty of different transformations for the transitional conserver.

In an experiment designed to test the "situational generality" of conservation, Uzigiris (1964) tested substance, weight, and volume conservation in a series of different "situations." Three different kinds of transformations were used with each of four different materials (making 12 combinations). The four materials were plasticene, metal cubes, wire coils, and plastic wire. Significant differences were found among scores for the four different materials. Now if the deformations of the plasticene and the rearrangements of the metal cubes are taken as examples of plastic-body transformations and rigid-body transformations, respectively, then a comparison of the proportions of conservers for these two materials actually represents a comparison of the two types of transformation. For 12-year-old subjects (N = 20), the proportions of volume conservers were 20 per cent for

plasticene, and 30 per cent for metal cubes. For a given material, the effects of different transformations are indicated by the proportions of subjects who conserve for either one or two of the three transformations. For conservation of volume, the proportion of such subjects was 5 per cent in all four materials for the 12-year-old subjects.

Uzigiris' transformations were, however, only marginally different from each other, and were arbitrarily selected rather than based on some theoretical position. Lovell and Ogilvie (1961a) found in the course of a weight conservation experiment that changes in "hardness" were very perceptually misleading. For example, 38 per cent of 50 eleven-year-old subjects thought that butter would weigh more if it were cooled and hardened. King (1961) found that 64 per cent of 103 eleven-year-old subjects thought that ice would weigh more than the corresponding amount of water. Vinh-Bang and Inhelder (Inhelder, 1968) found higher proportions of weight and volume conservers at a given age level for deformation of clay than for dissolution of sugar. For example, the proportions of 11-year-old subjects classed as conservers of weight were 96 per cent ($\underline{N} = 25$) for deformation of clay, and 78 per cent ($\underline{N} = 27$) for dissolution of sugar. Some transformations therefore (hardening of butter, freezing of water, dissolution of sugar) seem to be more "complex" than deformations of clay or restacking of blocks. Explanations for this complexity will be forwarded in Chapter V of the present study in relation to the data collected.

The need for the presence of both configurations in the comparison, the need for a variety of transformations, and the effects

of varying the transformation have been discussed. The final step in the conservation test is the actual comparison in terms of the physical quantity being tested. This comparison should be in terms of some objective operational measure (e.g. balance or displacement level), for two reasons.

The first reason is that it is impossible to be sure that the subject understands the question if it is asked with the use of terms like "same volume" or "just as heavy", especially since in their early stages of development, quantity concepts are undifferentiated or global. That is to say, "big" means "heavy" means "large" etc. Verizzo (1970) found that even for very bright children, terms like "mass", "weight", and "volume" were virtually synonymous. The second reason for the use of an objective measure of the physical quantity in the conservation test is that otherwise the subject may be led to think only in perceptual terms of the quantity being tested. In Piagetian theory, the achievement of conservation of a physical quantity means that the subject has progressed from (a) notions of the quantity in terms of the egocentric effects by means of which he came to be aware of it, to (b) understanding of the quantity in terms of objective interaction between bodies (Piaget & Inhelder, 1968, p. 59). Thus to ask, as some experimenters do, a comparison question like "Now is the sausage heavier than the ball, or lighter, or the same?" without reference to the weight on the balance, is to lead the subject to rely on egocentric notions of weight. For instance when Hyde (1970) tested weight conservation with the ball-sausage transformation, she actually asked subjects to heft the ball and sausage in their hands, thus inducing

them to answer in terms of their perceptual judgements. Some of Hyde's nonconservers of weight would likely have conserved if the question had been asked in terms of a balance.

Thus the fourth essential element in a conservation test is

D. use of an objective operational measure of the physical quantity being tested in the final comparison.

For weight conservation testing, the operational measure is relatively simple--the balance. The measure for volume in terms of displacement level of water on immersion of the configurations seems simple enough, but for a long time, at least until the age of 11 or 12 years, children do not understand the phenomenon of displacement of liquids (Piaget & Inhelder, 1968, Ch. VII). Children first explain the displacement in terms of a kind of struggle between the liquid and immersed object. In this "animistic" kind of displacement "law" the immersed object is thought to be pushing the water up. At later ages, children explain the displacement in terms of the weight of the immersed object. The results of the present experiment will show that up to 50 per cent of girls at grade 12 level still retain this erroneous notion that weight causes displacement. Therefore to many subjects the displacement law is not a measure of volume or space occupied.

The problem is overcome by Piaget and Inhelder in two ways: (a) by showing the subject at the start that it is the size of the immersed object that counts, not the weight, and (b) by asking the subject explicitly about the room or space occupied in the water by the immersed object (Inhelder, 1968, p. 344; Piaget & Inhelder, pp. 60-

61). A third control, substitution of a metal ball of the same size for the untransformed clay ball, is described by Piaget (Piaget & Inhelder, 1968, Introduction to Second Edition, p. xvii), but it is not clear whether this procedure was used in the original experiments. Inhelder (1968) makes no mention of this control in The diagnosis of reasoning in the mentally retarded, where the tests are described in practical terms, so it must be suspected that the control was not used in the original experiments. Furthermore, Vinh-Bang and Inhelder (Inhelder, 1968; Piaget & Inhelder, 1968) report two sets of proportions of volume conservers, one being of "a certain number of subjects explaining displacement by the action of weight" (writer's translation). For 11-year-old subjects, this proportion was reported to be 24 per cent (*N* = 25). It seems reasonable that volume conservation is related to the understanding that volume causes displacement, but it seems also that the displacement question alone is not a valid test of volume conservation.

Thus in examining the results of a volume conservation experiment, two aspects of the procedure should be looked for:

(a) whether the experimenter asked a pure displacement question, or whether there was explicit reference to room or space occupied, and

(b) if a pure displacement question was used, whether subjects were required to explain their answer, and if so, whether such explanations were used as criteria of conservation.

Criteria

Even if a conservation testing procedure has all of the elements

described in the previous section, it is still necessary to determine what criteria will be used to classify the subject as a conserver or nonconserver. In the Piagetian clinical method, the decision for a given subject is made by the experimenter on the basis of all of the statements and actions of the subject in the individual interview. No statement is taken at its face value, but the interviewer probes and cross-questions, being careful not to lead the subject, in a difficult and skilled technique (Flavell, 1963, pp. 28-29; Inhelder, 1968, pp. 343-346).

Although the clinical method is very powerful in determining thought structures hitherto unknown, it is difficult to do, time-consuming, and liable to subjective error. Where statistical analysis is desired, more standard techniques of testing are required. Such techniques may take different forms. Inhelder and Vinh-Bang (Inhelder, 1968) have developed a standardised form of the clinical method, described below (p. 40). Some experimenters (Beard, 1963; Goodnow, 1962, Lovell & Ogilvie, 1961) have employed more or less fixed schedules of questions in individual interviews, retaining final judgement by the experimenter as the criterion. Others (Elkind, 1961c, 1962; Teates, 1971; Verizzo, 1971) have administered prepared sets of questions to subjects in groups.

In any such standardised procedure, fixed criteria for classification as conserver or nonconserver have to be defined at the outset, but any such criteria must inevitably be somewhat arbitrary. A continuing controversy revolves around the question of whether subjects' judgements of equality of the initial and final configurations

are sufficient criteria for conservation, or whether subjects' <u>explanations</u> of their judgements should be taken into account. Goodnow (1962) and Goodnow and Bethon (1966) report two sets of proportions of volume conservers: one arrived at on the basis of judgements alone (volume 1), and the other on the basis of judgements plus explanations (volume 2). Elkind (1961a, 1961b, 1961c, 1962), Lovell and Ogilvie (1961), and Phillips (1971) required correct explanations as well as correct judgements. Brainerd (1971), Hermeier (1967), and Teates (1971) used only judgements as the criteria.

An excellent review of the judgements-explanations controversy is given by Brainerd (1972), who claims that a judgements-only criterion is to be preferred. Brainerd argues that to use explanations as criteria is to be unduly restrictive. He submits that the purpose of conservation tests is to infer the existence of thought structures, which according to Piaget are relatively independent of language. Therefore adequate explanations are sufficient but not necessary conditions for the inference of the presence of a given thought structure. In addition, an explanations criterion confines the response mode to the verbal, and this "unduly restricts the behavioral domain to which the theoretical construct (structure) applies." Thus explanations criteria are liable on two counts to result in failure to infer the existence of a thought structure that does exist, i.e. explanations criteria "are subject to at least two sources of systematic Type II error." Judgements, on the other hand, ". . . from the standpoint of Piagetian theory . . . are not subject to any known source of systematic error." Brainerd's argument assumes however that

possibilities of inferring a thought structure which does not exist (Type I error) can be reduced to insignificant levels with appropriate testing methodology, but the previous discussion of the displacement question (pp. 33-34) indicates that it is far from an easy matter to eliminate Type I errors from volume conservation testing.

Conclusions

A summary of the conclusions reached in the preceding discussion of conservation testing follows. The experiments reviewed in the subsequent sections of this chapter will be examined in the light of these conclusions.

1. The essential elements of a conservation test were seen to be:

   A. presence of both the final configuration and a comparison initial configuration,

   B. demonstration or at least description of the transformation,

   C. use of a variety of transformations, and

   D. use of an objective operational measure of the physical quantity being tested in the final comparison.

2. Any reported conservation test should be examined for the presence of these elements. Absence of A (both initial and final configurations demonstrated) probably results in overestimation of conservation levels through pseudo conservation. Absence of B (demonstration or description of transformation) makes the test one of estimation of quantity rather than conservation. Absence of C (use of

a number of transformations) probably overestimates conservation levels by including in the classification transitional cases. Absence of D (objective measure) may underestimate the conservation levels by leading subjects to rely on perceptual or egocentric notions of the physical quantity.

3. The use of judgement of displacement levels as the only criterion of conservation of volume probably results in overestimation of conservation levels because of misunderstanding by subjects of the phenomenon of displacement of liquids. The reports of procedures of volume conservation experiments should be examined for the use of either (a) prior stipulation to subjects that it is the volume (room occupied in the water) which causes the displacement, not the weight, or (b) explicit questioning of subjects about room or space occupied.

4. The use of subjects' explanations of their answers to conservation questions as criteria for the existence of conservation probably results in underestimation of the level of conservation, being too restrictive a criterion.

5. Two additional theoretical questions arose in the course of the discussion:

(a) What factors determine the relative difficulty of conservation questions for transitional subjects?

(b) Why is it that subjects who conserve weight for deformation of clay do not conserve in other more "complex" transformations like change of state?

RESEARCH RELATED TO PHYSICAL QUANTITY CONSERVATION

Research related to the original physical quantity conservation experiments by Piaget and Inhelder (1968) will now be discussed. It will be convenient to consider the research under two headings--replications, and relational experiments. Some experiments will be discussed under both headings. Only those aspects of the experiments reviewed which relate to conservation of weight and volume in older children (age 11 or above) will be discussed, and as a general rule, results quoted are excerpted from more extensive tables of results.

Replication and refinement

Using standardised procedures, testing of physical quantity conservation has continued at Geneva with the production of objective statistical data (Inhelder, 1968; Piaget & Inhelder, 1968). Proportions of conservers of substance, weight, and volume have been established at various age levels in groups of 25-30 subjects. For transformation of clay, 96 per cent of 11-year-old children were found to be conservers of weight, 80 per cent conservers of volume. For dissolution of sugar, 80 per cent of 11-year-old subjects were found to be conservers of weight, 57 per cent of volume. If the proportion of volume conservers is reduced by the numbers of subjects who explain displacement level in terms of weight, then 56 per cent of 11-year-old subjects conserve volume for deformation of clay. It was found also that learning of the displacement law (which implies conservation of volume) could be induced in two or three successive trials in which

subjects were required to judge the displacement level, observe the level experimentally, and explain the observed level. In the first trial, only 48 per cent of 27 twelve-year-old subjects gave correct explanations, but by the third trial, 92 per cent gave correct explanations. The standardised procedure used in these tests is still fundamentally a single-subject interview method. It consists of a "strategy in interrogation which . . . anticipates the various possible modes of reaction and prepares in advance a series of interventions" which enable the experimenter to interpret the reactions (Inhelder, 1968, p. 316).

The most notable replications of the weight and volume replications are those of Elkind (1961b, 1961c, 1962) and Lovell and Ogilvie (1961a, 1961b). In Elkind's procedures, the experimenter showed individual subjects (1961b) or groups of subjects (1961c, 1962) identical balls of clay, and asked them to predict whether the amount of clay would be the same if one of the balls was rolled out into a sausage. Subjects in groups recorded their responses on paper. The experimenter then actually performed the transformation, and asked students to judge whether the amount of clay in the sausage was the same as in the ball. Subjects were then asked to explain their answers. A score of one was assigned for a correct response so that subjects could score a possible three points for conservation of substance. For weight and volume conservation testing, the words "weight" and "volume" or "amount of room" were substituted for "amount". To be classed as a conserver a subject required a score of three, i.e. correct prediction, judgement, and explanation). In the

experiment performed with 469 junior and senior high school students, Elkind (1961c) found the following per cent of weight conservers:

grade 7 boys -- 71 (*N* = 56)
grade 7 girls -- 86 (*N* = 66)
grade 12 boys -- 100 (*N* = 14)
grade 12 girls -- 95, (*N* = 12)

and the following per cent of volume conservers:

grade 7 boys -- 38
grade 7 girls -- 26
grade 12 boys -- 79
grade 12 girls -- 68.

Elkind found also that sex and IQ were significantly related to volume conservation ability (see below p. 48, p. 50).

Now the standard procedures used by Elkind vary in two important aspects from the original procedures of Inhelder and Piaget. First, the subject's response to any one question is taken at its face value, in contrast with the probing and cross-questioning method of the Piagetian clinical method. Second, the volume question is asked in terms of space or room occupied by the transformed object, whereas the Piaget-Inhelder volume questions are asked in terms of space or room occupied <u>in water</u> by the transformed object. Whether or not the testing procedure is the cause, Elkind's surprisingly high proportions of subjects beyond the age of 11 who apparently do not have "abstract concepts of volume" appear to be anomalously high when compared with those found by Vinh-Bang and Inhelder (Inhelder, 1968; Piaget & Inhelder, 1968) or with those found by Lovell and Ogilvie (1961b).

The procedures used by Lovell and Ogilvie resemble a little more closely the Genevan method. Subjects were questioned individually with a pre-arranged but not inflexible set of questions.

Responses were not scored, but the experimenter judged whether the subject was to be classed as conserver, nonconserver, or transitional. The procedure for weight conservation (1961a) employed two balls of clay of different size and weight, the smaller one loaded with lead shot. Subjects were asked to judge which was the heavier. One was transformed in shape and again the subject was asked which was heavier. A significant difference from the Piagetian method is that the two initial spheres were not equal in weight to start with. The volume tests (1961b) were based on those described in The child's conception of geometry (Piaget et al., 1960), where wooden cubes are rearranged to form differently shaped solids with the same volume as a given solid block. Lovell and Ogilvie tested for interior volume, occupied volume, and "complementary or displacement" volume (i.e. the volume of the displaced water).

In the weight conservation experiment, of 168 eleven -year-old subjects 74 per cent were classed as conservers. Many of the conservers (up to 80 per cent) were found not to conserve in more complex transformations (hardening of butter, hardening of clay, freezing of water). The experimenters claimed also to have shown that the logical operation of transitivity could be applied to weight by subjects who were previously judged not to conserve weight. The problem here is that the form of weight conservation task used was itself a very difficult problem in transitivity, since the clay spheres were not initially equal in weight.[6]

In the volume conservation experiment, of 55 eleven-year-old subjects 74 per cent were classed as conservers of occupied volume.

These conservers correctly predicted that the same amount of water could be poured into a one-gallon can whether it contained a 2 x 3 x 2 or a 1 x 2 x 6 arrangement of cubes. When asked to explain their answer, these subjects stated either that the number of cubes was the same or that the arrangements of cubes "took up the same space". Now subjects who say in explanation that the number of cubes is the same may not be conserving occupied volume, because Lovell and Ogilvie failed to do what Piaget did, i.e. question the child explicitly about the "amount of 'room' taken up by the bricks in the water" (Piaget et al., 1960, p. 358). That some of these subjects explaining "conservation" of occupied volume in terms of the number of cubes may only be conserving weight is evidenced by the results from the tests for displacement volume. In one of these tests subjects were asked to compare the amounts of water displaced by the two different arrangements of cubes (1 x 2 x 6 and 2 x 3 x 2) when immersed in a can of water filled to the brim. Of the 11-year-old subjects only 78 per cent gave a correct response, but of these, only 53 per cent said that the same amount of water would be displaced by two cubes of different weight which are otherwise identical. If these subjects only are classed as conservers of occupied volume, then the proportion of 11-year-olds who conserve volume is 41 per cent. This compares with Elkind's figure of 25 per cent.

Elkind used only one test (the ball-sausage transformation), while Lovell and Ogilvie used five. This is an important difference in the light of the finding of Vinh-Bang and Inhelder (Piaget & Inhelder, 1968), referred to earlier, that the proportion of subjects

conserving volume increased in successive trials of the same experiment. Another difference is in the type of transformation involved. The Lovell-Ogilvie transformation was a rearrangement of already unitary cubes. Elkind's procedure was the shape change of a plastic continuous substance (modeling clay). Piaget recognised right from the start that "There is a good deal to be gained in avoiding the use of discontinuous elements . . . with older children who would otherwise be able to solve the problem by arithmetical correspondence without considering the volume as such (Piaget, et al., 1960, p. 356).

Lunzer (1961) also used a volume conservation test similar to that in The child's conception of geometry, but the sample was very small--"24 children ranging in age from 6 to 14". Lunzer concluded that the concept of physical volume "does not appear much before the age of 12."

In a limited replication of Elkind's experiments, Towler and Wheatley (1971) found that of 71 female college students, median age 18, 96 per cent conserved weight and 61 per cent conserved volume. It was erroneously concluded that since the concept of "metrical continuity"[7] is thought by Piaget to be prerequisite to volume conservation, if "some college students fail to understand the conservation concept, then it follows that they have not developed an adequate concept of metrical continuity or other concepts upon which the former are dependent." One might as well argue that since weight conservation also is a prerequisite to volume conservation, then the volume nonconserver must also be a weight nonconserver. Towler and Wheatley claim that their results suggest that at least part of the

problem is the fault of "inadequately formed concepts of atomism." On the contrary however, if adequate atomistic concepts are the very expression of the solution of the volume conservation problem (see p. 25), then the lack of such concepts is symptom rather than cause of the nonconservation of volume.

Phillips (1971) sought to show the existence of a sequential set of conservation concepts which lead to conservation of displacement volume. A selected number of steps in a hypothetical sequence was chosen for investigation--continuous quantity, interior volume, displacement volume with water as the displaced medium, and displacement volume with discontinuous blocks as the displaced medium. Phillips' procedure was an individual interview technique, but half of the subjects were shown pictures of the successive steps in the transformations rather than the transformations themselves. The volume conservation transformations were similar to those in The child's conception of geometry (Piaget et al., 1960), i.e. rearrangements of arrays of cubes. Subjects were questioned about the levels of the displaced media when different arrays of the cubes were immersed. To be classed as a conserver a subject had to correctly predict the level after the transformation and correctly explain the predictions. Of 40 grade 7 subjects, 45 per cent were classed as conservers of displacement volume when water was the displaced medium, and 48 per cent when blocks were the displaced medium. Two other subjects were previously eliminated from consideration on the basis of a pretest. Phillips appears to mean occupied volume by his term "displacement volume". At least his tests are concerned with, if anything, occupied volume. He does not

mention occupied volume, and discusses "displacement" volume as compared with interior volume. The tests involve only judgements about displacement levels, and subjects were not questioned about room or space occupied by the arrays of cubes or room or space available to the displaced medium. Correct explanations were required for a subject to be classed as a conserver, and Phillips' proportions of conservers are close to the "corrected" proportion of 41 per cent conservers of occupied volume derived above (p. 43) from the figures of Lovell and Ogilvie. There was no evidence that the kind of displaced medium (continuous or discontinuous) made any difference, but not surprisingly, the sequence of attainment conservation of continuous quantity, conservation of interior volume, conservation of 'displacement' volume was verified.

Brainerd (1971) treated occupied volume conservation as an index of the existence in a subject of the proportionality scheme. He sought evidence that this scheme does not appear until the formal operational period and that the concept of density depends on the concept of volume. Accordingly, Brainerd's results indicate that both volume conservation and the density concept are achieved by increasing numbers of subjects between the ages of 8 and 15, that the two are correlated, and that volume conservation is prerequisite to the density concept.

Subjects were tested individually with a prerecorded protocol. The tests for density involved the principle of flotation--subjects were asked whether successively smaller pieces of clay would float on water. The tests for volume conservation used transformations of

(a) a clay ball ("solid volume"), and (b) a glass of water ("liquid volume"). For solid volume conservation, subjects were shown the displacement level on immersion in water of a clay ball, which was then transformed into a sausage. Subjects were then asked if the displacement level would be different if the sausage were to be immersed. For liquid volume, subjects were shown two identical glasses of water and asked if the water in each glass took up the "same amount of space or room." The water in one glass was poured into another of different shape and subjects were again asked if the water in each glass took up the same amount of space or room. In both solid volume and liquid volume tests, the subject was required to justify his answer, but subjects were classified as conservers on the basis of their answers to the conservation questions, not of their explanations of their answers.

Of 72 subjects (24 in each of grades 3, 6, and 9), 57 per cent were classed as conservers of solid volume, and 72 per cent as conservers of liquid volume. Though no tabulation of conservers by grade is given in the article cited, in a private communication Brainerd gives the following data:

per cent of conservers, solid volume, grade 6 = 67
per cent of conservers, liquid volume, grade 6 = 93
per cent of conservers, solid volume, grade 9 = 88
per cent of conservers, liquid volume, grade 9 = 100.

Again, since the solid volume test made no mention of room or space occupied, the proportion of conservers is probably an overestimate. The liquid volume test is an invention of Brainerd's, and is equivalent to the purely verbal test used in the present experiment. In the absence of the control afforded by the use of an operational measure

of volume (water level in the strict Piagetian test), it is possible that in these two tests, some subjects classed as volume conservers may be conserving merely quantity of matter or interior volume.

Relational Studies

Various studies have attempted to relate conservation of physical quantity to variables like age, sex, intelligence, race, cognitive style, and so on. As before, reports of these studies will be examined only to the extent that they relate to the present study, so that results pertaining to conservation of quantities other than weight and volume will not be discussed. Where figures are quoted, these are excerpts from more extensive tables of results.

Mental Ability. In the experiment with junior and senior high school students which was described above (p. 41), Elkind (1961c) found a significant positive correlation between IQ and conservation of volume (point-biserial = 0.31).

Hermeier (1967) compared the proportions of conservers of substance and of volume among groups representing three levels of IQ, and found significant differences among these proportions. Hermeier used an individual interview technique with prearranged questions. For volume conservation testing, subjects were shown the ball-pancake deformation of clay, and were asked simply whether the levels in two identical containers of water would be the same upon immersion of the ball as of the pancake. On the basis of this single test Hermeier classified 47 per cent of his 12-year-old subjects as conservers of volume.

Verizzo (1970) tested 140 subjects of "very superior" intelligence (135-154 on Weschler scale), aged from 7 to 14, on a wide range of conservation tasks including weight and volume. A "displacement of volume" test was included, but no explanation was given by Verizzo of the nature or aim of this test--presumably it tested understanding of the displacement law. A demonstration-with-oral-questions technique was employed with groups of students in a normal school setting. The actual tests for volume conservation were not described. Verizzo found that the very bright children generally achieved the various conservations at an earlier age than is usually found for "normal children", although no actual comparison with groups of normal children under the same test conditions were made.

The per cent of weight conservers found were

grade 6: 95 per cent

grade 8: 91 per cent,

and of volume conservers

grade 6: 80 per cent

grade 8: 59 per cent (N approximately 30 each grade).

Verizzo concluded that for many subjects, the terms mass, weight, and volume were virtually synonomous, and that for his very bright subjects ". . . volume and displacement volume proved troublesome even to a substantial percentage of older students."

Goodnow and Bethon (1966) found both mental age and IQ to be significantly related to conservation ability. An "increasing proportion of success with increasing MA" in conservation tasks was found, as were significant differences between proportions of conservers

in groups of different mean IQ. The tests were administered to subjects individually with a sequence of prepared questions based on the protocols reported by Piaget in various works. The weight and volume conservation tests employed the ball-pancake transformation. For volume, subjects were asked to predict water levels which would result from immersion of the ball or the pancake and to explain their answers. Those who correctly predicted the displacement level were classed as "volume 1" conservers. If the subject's explanation did not refer to weight, then the subject was included in the category "volume 2". Thus volume 2 subjects both predicted and explained correctly. The proportions of volume 1 and volume 2 subjects in the different IQ groups are summarised in Table 1.

Sex. Elkind found that significantly higher proportions of boys than of girls were conservers of volume in junior and senior high school (1961c) and in college (1962). For college students he found that the proportions of volume conservers increase with age for females only. In other experiments, Beard (1963) found a sex difference in volume conservation performance, but Leon (1972) and Bat-Haee (1971) did not.

Leon (1972) tested 182 subjects in grades 7, 8, and 9 for conservation of substance, weight, and volume. The tests were similar to those of Elkind, and included a test for conservation of "liquid volume". This "liquid volume" test was in fact no more than the classical Piagetian test for conservation of continuous quantity, which is attained by most subjects by the age of seven (Piaget, 1965). To test for sex difference, Leon compared boys' and girls' total

TABLE 1

PER CENT OF VOLUME CONSERVERS IN DULL, AVERAGE, AND SUPERIOR 11-YEAR-OLD BOYS (GOODNOW & BETHON, 1966)

	Dull Boys	Average Boys	Superior Boys
Volume 1	28	62	75
Volume 2	12	38	56

conservation scores--that is, scores derived by combining substance, weight, volume, and continuous quantity conservation scores. Any sex difference in volume conservation would thus be masked by the high scores obtained by subjects of both sexes on the substance, weight, and continuous quantity tests.

Bat-Haee (1971) also used a procedure similar to Elkind's, but instead of classifying subjects as conservers and nonconservers, he derived total scores for each quantity conservation. Thus a subject could score a possible three points for volume conservation by correctly predicting, judging, and explaining the invariance of volume in the ball-sausage transformation. Bat-Haee then sought to find sex differences by performing an analysis of variance on these limited scores for boys and girls. The means for volume conservation in the oldest subjects (grade 6) were only 0.64 for boys, and 0.80 for girls. On Elkind's criterion (score of three) there could have been no more than six male conservers, and eight female conservers among thirty boys and thirty girls.[8] Perhaps there were none, even by Brainerd's judgements-only criterion. Bat-Haee's results do however tend to confirm findings in other experiments that volume conservation does not appear before 11-12 years. It is not surprising that no significant difference is found between boys and girls in an ability that neither has developed.

Brainerd (1971) found no sex differences in an experiment connected with volume conservation, even though the sample included grade 9 subjects. There were however only 12 subjects of each sex in the grade 9 group. A sex difference of the magnitude found by Elkind

would be unlikely to show up in a sample this size.

In tests purporting to measure volume conservation, in subjects aged from 5 to 9, Beard (1963) found higher proportions of conservers among boys than among girls. Four tests were used in an individual interview technique:

a. Balls of clay were immersed in identical glasses of water. Subjects watched as one ball was flattened into a pancake and were required to say whether for the pancake the water would rise the same amount.

b. The level of water in a glass was noted, salt was added, and the level noted again. Subjects were required to predict what the level would be after dissolution of the salt.

c. Subjects were shown a ping pong ball and an equal-sized ball of plasticene. They were shown the level of water on immersion of the ping pong ball, and asked whether the water "would go up just the same amount, or more or less" upon immersion of the plasticene. The question was repeated for a hypothetical "very heavy stone" of the same size.

d. A cylinder was placed with its axis vertical in one of two identical glasses of water. Subjects were required to predict whether the water level would be the same for an identical cylinder immersed in the other glass, with its axis horizontal. In each case, subjects were required to justify their predictions. Beard does not specify how a subject was classified as conserver or nonconserver, but presumably the interviewer judged on the basis of the child's predictions and explanations. There were no questions referring

explicitly to room or space occupied. The following per cent of volume 'conservers' were found for five-year-old subjects ($\underline{N}$ = 35):

ball-pancake. 29

salt solution 30

ping pong ball. 9

cylinders 27,

and for 9 year-old-subjects ($\underline{N}$ = 32):

ball-pancake. 31

salt solution 48

ping pong ball. 9

cylinders . . . . .38.

Now the only test which involves a difference in weight for the immersed objects is the ping pong ball test, and the proportion of conservers in that case is very low. It is strongly to be suspected that in the other cases the subjects classed as 'conservers' were conserving weight, or perhaps just quantity of matter. Probably their explanations revolved around phrases like "just as big" or "same amount." In any case, the sex difference found by Beard was significant for each task except the ping pong ball test. Perhaps this represents a sex difference in weight conservation, or possibly more girls than boys at the age levels tested believe in an animistic displacement law.

Of the other studies reviewed in this chapter, some tested single-sex groups, others make no mention of sex differences sought or found, although Inhelder (Tanner & Inhelder, 1958, p. 63) mentions sex differences "in the formation of spatial representation" found in Genevan experiments. Whether or not it has its roots in earlier grades,

the sex difference found by Elkind (1961c) in volume conservation among secondary school and college students is the only reasonably conclusive finding related to conservation achievement sex differences.

Other Relational Studies. Leon (1972) in the study referred to above (p. 50) found evidence for relationships of "conservation ability" (a composite of scores on substance, weight, and volume tests) with race, grade, and science achievement. Simpson (1970) reports finding that chronological age and the cognitive styles Reflection and Impulsivity are factors in conservation, with chronological age a "greater factor." Simpson's procedures were similar to Elkind's. Goodnow and Bethon (1966) found that schooling did not affect the level of acquisition of volume or weight conservation in boys from 10 to 13 years.

In a prior study, Goodnow (1962) sought relationships between quantity conservation and "social milieu"--a global description involving racial, socio-economic, cultural, and educational differences. Goodnow found that "variations in nationality, social status, and schooling make no essential difference to success (on the conservation tasks)." The procedures used by Goodnow have been described above (p. 50). According to one of Goodnow's graphs, reproduced in part in Figure 1, more European students conserve volume (volume 2) than Chinese students after the age of 11 years. Goodnow suggests that the source of this difference is the variation in the type of science courses studied by these two groups in their normal schooling.

A study by Teates (1971) however detected no difference in weight or conservation levels between two groups of grade 9 students who

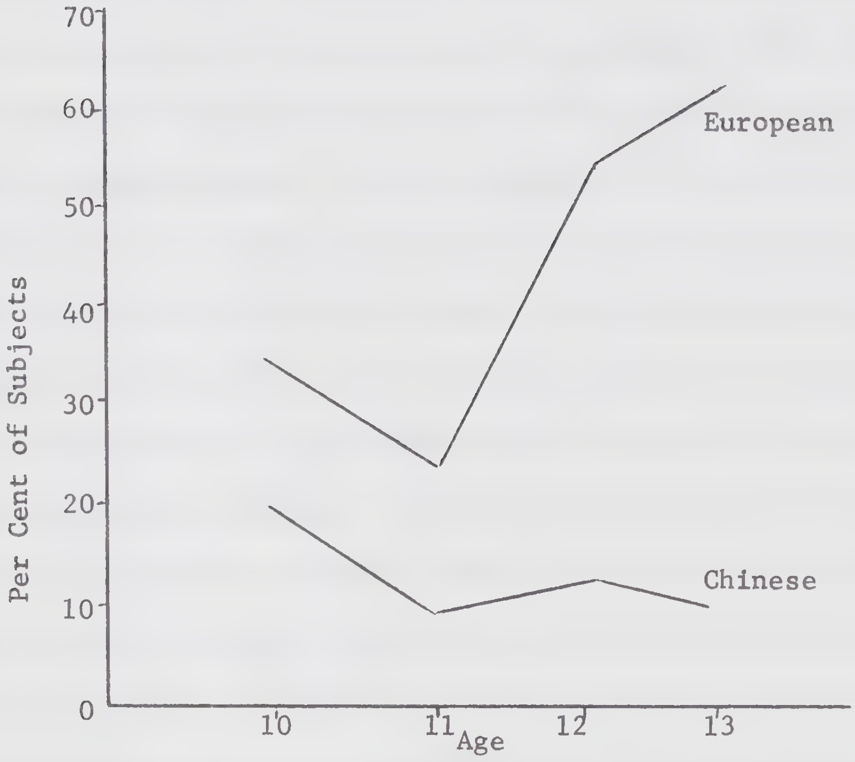

Figure 1

Per Cent of Volume 2 Conservers Vs. Age for European
And Chinese Students (Bethon, 1962)

had studied different science courses in junior high school. Teates used group administration of tests, and presented the tasks by means of tape-recorded questions, with configurations and transformations illustrated by means of projected slides. Two kinds of volume question were used. One was a pure displacement level question, with deformations of clay as the transformations. No mention was made of room or space occupied. In the second kind of question, subjects were shown pictures of arrays of blocks, and in each case were required to imagine an aquarium of similar shape. The arrays were changed (e.g. from T-shaped to L-shaped) and subjects were required to say in each case if the aquarium in its new shape would hold as much water as the aquarium in the old shape. This kind of question obviously tests interior volume, not occupied volume. A subject was required to answer each of six questions correctly in order to be classed as a volume conserver. Teates tested 568 grade 9 students and classified 87 per cent as conservers of weight, and 23 per cent as conservers of volume. The proportion of volume conservers seems to be excessively low, especially in view of the nature of the questions (displacement-question-only and interior volume). Possibly the all-or-nothing criterion was too stringent, and the mode of administration (taped protocols with projected slides) was not conducive to accurate results.

SUMMARY

A short recapitulation of the chapter follows, commencing with a brief restatement of the Piagetian theoretical framework of the

study. The main points made in relation to the methodology of conservation testing will be reviewed, and the survey of the research literature summarised.

1. The following theoretical framework was derived from the works of Piaget: Concepts of physical quantity are not developed immediately or all at once upon contact with appropriate experience, but are developed in an invariable sequence--substance first by the age of about 7-8, then weight by the age of about 10, then volume commencing at the age of about 11 or 12. Each concept in turn is attained by the achievement of a grouping of concrete operations, and this achievement is accompanied by conservation of that quantity. A particulate theory of matter (atomism) develops spontaneously in the subject as he develops the physical quantity concepts, the final achievement of volume conservation being marked by development of the atomistic scheme of compression and dilatation. Certain problems requiring formal operational schemes for their solution have to be worked out before volume can be conserved. Such schemes do not usually appear before the twelfth year.

2. Methodology was advanced as a major variable in volume conservation experiments, so that results of any given experiment have meaning only in the context of the specific method of testing in that experiment. The essential elements of a conservation test were analysed as (a) presentation of both configurations for comparison, (b) demonstration or at least description of the transformation, (c) use of a variety of transformations, and (d) comparison of configurations in terms of some objective operational measure of the

quantity being tested. The relative difficulty of conservation for different transformations was discussed. Prior stipulation of room occupied as the cause of displacement, or explicit questioning about room or space occupied, were shown to be important aspects of volume conservation testing often absent in reported research. A cogent, theory-based argument for the use of judgements-only as criteria for the existence of conservation rather than judgements-plus-explanations was reported.

3. Replications of Piagetian tests for conservation and related experiments were seen generally to support the invariable order and average ages of acquisition of conservations as found by Piaget. Table 2 presents a summary of the proportions of conservers of weight and volume found in the various studies reviewed, with brief notes regarding the testing method used. The contents of this table leave little doubt that conservation of weight is well established by most subjects by the age of ten, and that volume conservation does not begin to be established by most subjects until at least the twelfth year. In fact the issue of volume conservation is far from clear. Somewhere between 20 per cent and 80 per cent of 12-year-old subjects conserve physical volume. Evidence was reported that

(a) many subjects in secondary school grades do not conserve volume,

(b) more girls than boys in secondary school grades do not conserve volume,

TABLE 2

SUMMARY OF REPORTED LEVELS OF CONSERVATION

Experimenter(s)	Subjects' age	Subjects' sex	Per Cent of Conservers Weight	Per Cent of Conservers Volume	Remarks
Vinh-Bang & Inhelder	11		96	80	deformation of clay
	11		80	57	sugar dissolution
	11			56	deformation of clay, excluding subjects who say weight causes displacement
Elkind	12	M	71	38	
	12	F	86	26	
	17	M	100	79	
	17	F	95	68	
Lovell & Ogilvie	11		74	74	
	11			41	"corrected" for subjects who think weight causes displacement
Towler & Wheatley	18	F	96	61	Female college students
Phillips	12			45	
Brainerd	12			67	"solid volume"
	12			93	"liquid volume"
	15			88	"solid volume"
	15			100	"liquid volume"
Hermeier	12			47	
Verizzo	11		95	80	superior IQ students.
	13		91	59	
Goodnow & Bethon	11			62	"Volume 1" average IQ boys
	11			38	"Volume 2" average IQ boys

(c) attainment of volume conservation is related to IQ, and

(d) attainment of volume conservation might be influenced by schooling.

FOOTNOTES - CHAPTER II

1. *Le développement des quantités chez l'enfant*.
2. Physical or infralogical operations are discussed by Flavell (1963, pp. 196-198). Essentially they represent movements which are spatio-temporal in nature.
3. " . . . seul un atomisme, implicite ou explicite, dégageant les rapports de compression ou de décompression des grains, conduira ainsi à l'invariant de volume physique."
4. The complex sequence of steps in the attainment of volume conservation is described at length by Piaget and Inhelder (1968, pp. 314-325).
5. A step by step description of this procedure is given in *Le développement des quantités*, pp. 60-61.
6. S first has to decide that the larger ball is lighter than the smaller (loaded) ball, then that the sausage is the same weight as it was when it was the larger ball, then deduce that the sausage must be lighter than the smaller ball. There are no asymmetrical relations in the transitivity problem, as there are in the 'conservation' problem.
7. By metrical continuity Towler and Wheatley apparently mean the ability to visualise a volume as an infinite set of areas and hence to relate interior volume to boundary surfaces (Piaget, et al., 1960, p. 371).
8. A mean of 0.80 for 30 girls results from 24 correct responses. The maximum possible number of subjects who could have scored the

possible three items correct is therefore eight. More likely, a large proportion of the 24 correct responses were correct-prediction-only patterns, representing pseudo conservation.

CHAPTER III

DESIGN OF THE EXPERIMENT

In general terms the essential purpose of the experiment now to be described was to test conservation of weight and volume in secondary school students, and to relate conservation to three variables: school grade, sex of subject, and methodology of testing. First the rationale for selection of the sample, and the sample itself will be discussed. The design of the tests will then be described and justified. Finally, the actual administration of the tests and the subsequent analysis of the data will be outlined.

THE SAMPLE

Since low proportions of nonconservation response were expected for some questions, a relatively large sample was required. This would allow statistical meaning to be attached to low frequencies. The initial aim was 150 subjects per grade, in grades 7 through 12, so that a proportion as low as five per cent would represent a frequency of 7 or 8. To obtain such a large sample by random selection from a larger population would have presented great difficulties in administration of the tests, since subjects would have had to be interviewed individually (a very time-consuming process), or grouped in some specially arranged time and place (which was not feasible). An alternative might have been to select normal class groups from some population of groups, but to do this would have been to introduce an

unwanted and certainly important variable into the problem--classroom experience. Possibilities for generalisation from results obtained in a few functioning class groups would have been very limited.

The decision reached was to employ as the sample all of the secondary students in a single school authority. This would ensure a large enough sample which would include subjects in all ranges of ability and achievement, and with a reasonable homogeneity of classroom experience. The price of course could be the possibility of large scale bias in ability, curriculum experience, and so on. Once the study was completed however, replication on a smaller scale with selected homogeneous groups could check for level of generalisability.

The school authority chosen was the County of Wetaskiwin No. 10, which is responsible for the education of students in a large farming district near the city of Edmonton, Alberta, Canada. A total of 906 students in grades 7 through 12 were present at the 10 schools in the county on the days when tests were administered. Absent students were simply omitted from the sample. The age, grade, and sex distributions of the 106 subjects are presented in Table 3.

Ideally, the population represented by the sample is all secondary school students. More realistically, it is probably all rural Alberta secondary school students, but a limited comparison of the sample with the rest of the students in the province was possible. Early in 1972, the Alberta Department of Education administered standardised tests of achievement and ability to grade 9 students throughout the province. At the time this was an annual exercise. Results of these tests were available for most of the grade 9 students

TABLE 3

DISTRIBUTION OF SUBJECTS BY AGE, GRADE, AND SEX

	GRADE					
	7	8	9	10	11	12
AGE	M (F)	M (F)	M (F)	M (F)	M (F)	M (F)
11	1 (0)					
12	30 (31)					
13	57 (60)	41 (41)	0 (1)			
14	15 (5)	61 (62)	30 (32)	1 (0)		
15	1 (3)	16 (5)	54 (69)	25 (14)		
16	3 (0)	2 (0)	14 (4)	30 (23)	14 (16)	2 (1)
17			3 (0)	9 (3)	26 (24)	11 (19)
18					4 (2)	19 (21)
19					0 (1)	
TOTAL	107 (99)	120 (108)	101 (106)	65 (40)	44 (43)	32 (41)

in the sample (93 of the 106 girls, 79 of the 101 boys). The test results used here were those of an Alberta Department of Education science achievement test, and the Cooperative School and College Ability Test (Form 3A)--SCAT--together with its verbal and quantitative subtotals. Tables 4 and 5 present the results of chi-square goodness of fit tests of the distribution of scores on these tests in the grade 9 subjects in the sample with the distribution of scores in the province as a whole. Deciles in the cases of science achievement and SCAT tests are compared with a rectangular distribution, and stanines in the cases of the SCAT verbal and quantitative subtotals are compared with normal distributions. No significant chi-squares are associated with these comparisons, therefore it may be concluded that the sample tested is not seriously biased in science achievement or ability with respect to students in the province of Alberta as a whole.

DESIGN OF THE TESTS

Tests were designed to be administered to subjects in groups, rendering feasible the testing of the large sample. The full test was designed to occupy one normal 40-minute school period, and consisted of 46 items--18 weight conservation questions, 12 volume conservation questions, 8 displacement law questions, and 8 atomistic schemes questions. The actual questions will be described in subsequent sections of this chapter, and specific details may be found in Appendix A. Except for the atomistic schemes questions, the method of testing was an adaptation of that used by Elkind. Questions

TABLE 4

GOODNESS OF FIT OF RECTANGULAR DISTRIBUTION TO OBSERVED DISTRIBUTION OF DECILE RANKS IN SCIENCE ACHIEVEMENT AND SCAT (TOTAL)--GRADE 9 SUBJECTS

Decile Rank	O	E	$\frac{(O - E)^2}{E}$
		Science Achievement	
0-1	15	26.5	4.66
2	15	17	0.24
3	18	17	0.06
4	22	17	1.47
5	13	17	0.94
6	23	17	2.12
7	20	17	0.53
8	22	17	1.47
9-10	24	26.5	0.05
Total	172	172	$11.54 = \chi^2$, df = 8, $p > 0.10$
		SCAT (Total)	
0-1	18	26.5	2.38
2	19	17	0.24
3	25	17	3.74
4	11	17	2.12
5	14	17	0.52
6	22	17	1.47
7	22	17	1.47
8	18	17	0.06
9-10	23	26.5	0.35
Total	172	172	$12.38 = \chi^2$, df = 8, $p > 0.10$

TABLE 5

GOODNESS OF FIT OF NORMAL DISTRIBUTION TO OBSERVED DISTRIBUTION OF STANINES IN SCAT VERBAL AND SCAT QUANTITATIVE SUBTOTALS (GRADE 9)

Stanine	0	E	$\frac{(0 - E)^2}{E}$
SCAT Verbal Subtotal			
1-2	15	19	0.84
3	22	20	0.20
4	32	29	1.68
5	39	34	0.74
6	37	29	2.20
7	16	20	0.80
8-9	9	19	5.25
Total	170	170	$11.71 = \chi^2$, df = 6, $p > 0.05$
SCAT Quantitative Subtotal			
1-2	19	19	0.00
3	15	20	1.25
4	26	29	1.68
5	27	34	1.44
6	44	29	7.75
7	19	20	0.05
8-9	20	19	0.05
Total	170	170	$12.22 = \chi^2$, df = 6, $p > 0.05$

were asked orally with demonstrations, and subjects recorded their own responses on answer sheets. This method was chosen in order to make the tests as non-verbal as possible and in an attempt to ensure that misunderstanding of any question was minimised. Accordingly, students were encouraged to ask clarifying questions at any time.

Conservation Testing

The conservation questions were framed with four main considerations. These considerations will be examined in turn before the form of the questions themselves is discussed.

1. It is more desirable to avoid incorrectly classifying a subject as a nonconserver than to avoid incorrectly classifying a subject as a conserver. This is because the experiment aims to identify the level of nonconservation, and the conservative course is under-estimation of this level.

2. An adequate quantity concept is characterised by necessary conservation, i.e. conservation seen as a logical necessity rather than as an empirical possibility. Piaget (Piaget & Inhelder, 1968, p. 71) describes necessary conservation this way: "psychologically it seems as if there is no problem for the child: conservation is asserted by him as if he never thought otherwise" (writer's translation).

3. Administration of the tests should be facilitated as far as possible without compromising experimental accuracy.

4. There should be basic similarity with the original Piagetian tasks, since interpretation may be difficult otherwise. In other words the essential elements of a conservation test described

above (p. 37) should be present. Briefly, these elements are (a) presence of both configurations in the final comparison, (b) demonstration (or description) of the transformation, (c) use of a number of transformations, and (d) comparison in terms of an objective operational measure of the quantity being tested.

In some of the questions, one or more of these essential elements was absent. Although the initial configuration was both demonstrated and described in every case, the actual transformation was not always demonstrated. In some questions (6, 12-15, 17, and 18) the transformation was described and simulated, and the final configuration merely described. In other questions (1-5, 7, 9, 11, and 16) comparison forms of the initial configuration were not used. In the light of the analysis of conservation testing in Chapter II (pp. 27-37) it may be concluded that (a) the effects of substitution of description and simulation of the transformations for actual demonstration would probably be insignificant, and (b) in the weight conservation questions (1-18) the levels of nonconservation found will probably be underestimated, because in no case are both configurations demonstrated simultaneously. In view of consideration 1 above (p. 70), this underestimation of nonconservation is less undesirable than overestimation.

The method of recording response choices was decided on the basis of consideration 2 (testing should be for necessary conservation). In each task, the final question was asked in a form such as "If I put it back on the balance, will the weight be more, will it be less, or will it be the same?" The subject's response choice was then one of

"more", "less", or "the same." A fourth or "don't know" choice was not provided, because anything less than necessary conservation was classed as nonconservation. To force a choice meant that some nonconservers were probably classed as conservers, again making the level of nonconservation found an underestimate. A uniform answer code was maintained throughout--for the choice "more" the subject would mark A on his answer sheet, for "less" he would mark B, and for "the same" he would mark C. This uniform code avoided confusion, but the answer to a conservation question is always the same. To minimise the consequences of this--the possibilities that students might establish a response set, recognise a pattern, try to vary their responses etc.--some questions were included for which the response would be other than C (the same). Again, the likely possibility would be for students to discern a response pattern and conserve spuriously, making the level of non-conservation an under estimate. Two of the questions which were included to vary the response served also to estimate a correction for inattention. These questions (11 and 18) were designed to be "obvious" to any subject attending.

Weight Conservation Test

The weight conservation questions were designed to test for conservation in simple transformations like change of shape, in complex transformations like change of state, and to provide data for analysis of nonconservation in the complex transformations. The complex transformations used were:

question 12: heating to redness of a metal bar

13: melting of ice in a sealed plastic bag
14: evaporation of gasoline inside a sealed metal can
15: partial burning of paper inside a sealed glass jar.

The simple transformations used were selected to represent separable apparent physical aspects of the complex transformations. They were:

question 1: sectioning of a cylinder of clay
2: joining of a straight stick of clay into a ring (shape change)
3: raising the height of a clamp on a metal stand (vertical displacement of centre of mass)
4: mixing of water with syrup in a beaker (density change)
5: inversion of conical pyrex flask (pressure change)
6: setting to hardness of a jelly solution (liquid-solid change)
7: displacement of a wooden block relative to its initial position on the balance platform
8: comparison of one teased out cotton wool ball with two unchanged previously identical balls (density and volume change)
9: compression of a fixed mass of cotton wool inside a sealed glass jar (density and volume change inside an externally unchanged system)
10: compression of a styrofoam sphere (volume and density change)
11: sand added to jar partly filled with sand (obvious question)
16: oxygen released from a metal cylinder (gas has weight concept)
17: football of fixed shape and size pumped hard with air (gas has weight concept)
18: alcohol burner burned for half an hour then extinguished (obvious question).

All physical aspects of the complex transformations are thought to be represented in the simple transformations. The list of simple transformations was derived from a preliminary analysis of the complex transformations in physical terms, conducted with the assistance of a panel of experienced science teachers and professors of science

education in a graduate seminar at the University of Alberta.

A consistent procedure was adopted for administering the questions. Subjects were first shown an OHAUS triple-beam platform balance (2610 g) and asked if they knew what it was (similar balances were to be found in the science laboratories of each of the schools where subjects were tested). The experimenter then said "The balance is used to weigh things. I'm not actually going to weigh anything, but I could. Let's suppose I weighed this piece of modeling clay. It might be 210 grams or four ounces or something. Now suppose I do this. Watch. I break the clay into a number of pieces. Now if I put the pieces back on the balance, and if I weigh it again, will the weight be more, will it be less, or will it be the same?" The same procedure was adopted in each of the questions, but in questions 6 (setting of jelly), 9 (compression of cotton wool), 13 (melting of ice), 14 (evaporation of gasoline), and 15 (burning of paper) where in each case a sealed container is involved, subjects were told in addition "Nothing gets in, nothing gets out."

Volume Conservation Test

Twelve volume conservation questions were designed involving six different transformations; three rigid-body transformations, and three plastic-body transformations. For each transformation two questions were asked--a verbal question in terms of volume of, or room occupied by the body, and a displacement question purely in terms of displaced levels of water.

A consistent form of administration was adopted. After each

transformation was demonstrated or described, subjects were asked the verbal question "Does it (the final configuration) now have a greater volume, a smaller volume, or the same? Does it take up more room, less room, or the same?" Then followed the displacement question "When it was like this (the comparison initial configuration) if I put it in the water the level would rise. Now that it's like this (final configuration) if I put it in the water would the level rise more, would it rise less, or would it rise the same?" Since the displacement question always immediately followed the verbal question, demonstration or simulation of the transformation was not repeated.

The wording of the verbal question was not chosen arbitrarily. "Taking up room" (prendre de la place) was the terminology used in the original Piaget-Inhelder experiments (1968), but, in case this term should be confusing to sophisticated students the term "volume" was used in addition. "Volume" alone could however mean no more than interior volume or quantity of matter to many students.

In question pair 19-20, the transformation was the folding out of a hinged pair of identical wooden square prisms, rather like the folding out of a pocket knife, except that the two wooden parts did not intermesh. In 21-22, it was the unfolding of a strip of lead foil. In 23-24, it was the separation into two roughly equal pieces of a blob of clay. The blob had been neatly pre-cut and rejoined prior to administration of the test. These three question pairs represent rigid-body transformations. In question pair 25-26, the transformation was the ball-sausage change. In 27-28 it was the pressing flat into a "pancake" of a ball of clay. In 29-30 it was the melting of an ingot

of solder metal in a porcelain crucible and subsequent solidification on an asbestos sheet into an irregular lamina. This transformation was simulated. The latter three question pairs represent plastic-body transformations. Complete specifications for all initial and final configurations are presented in Appendix B.

Displacement Law Test

The displacement law questions were based on procedures used by Piaget and Inhelder. The form was the same for six of the eight questions--an object was immersed in water in a 1000 ml graduated cylinder, the new level noted, and the object removed. Subjects were then shown a second object and asked to predict whether if it were immersed in the same container of water, the level would rise more, would rise less, or rise the same. In no instance was the second immersion actually performed. The questions may be summarised as follows:

question	first object	second object
31	lead sphere (2.0 cm) (dia.)	lead sphere (2.5 cm)
32	lead sphere (2.5 cm)	aluminum sphere (2.5 cm)
33	lead sphere (2.0 cm)	aluminum sphere (2.5 cm)
34	block of wax (5.2 x 2.3 x 1.2) cm^3	lead sphere (2.5 cm)
35	aluminum cylinder (2.5 cm (diam) x 7.5 cm (length)) axis vertical	same cylinder, axis horizontal
36	4 oz sealed jar 1/3 full of sand	same jar, completely full of sand.
38	aluminum cylinder immersed to half depth of water	same cylinder immersed to full depth of water

In question 36, a 1000 ml pyrex beaker was used instead of the graduated cylinder, and it was demonstrated that the lighter jar would

sink. In question 38, subjects were asked to predict whether if the same aluminum cylinder were immersed first in the graduate then in the beaker both initially filled to the brim, the same amount of water could be collected as overflow. Question 31 forms an "obvious" question and sets a limit on the number of subjects who did not answer the question. Less than 40 subjects or 4 per cent answered question 31 incorrectly. As in the previous 30 questions, the answer code for the displacement law questions was A = more, B = less, and C = the same.

Atomistic Schemes Test

The final eight questions were designed to test subjects' atomistic schemes of compression and dilatation. It was assumed that any schemes would be equally well applied by subjects to one situation or transformation as to another, so that a total score on a test which involves a number of different transformations is a meaningful statistic.

A pool of 16 multiple choice items was prepared and pretested with two grade 7 and two grade 9 classes at an Edmonton public school. On the basis of an item analysis, the number of items was reduced to eight. Individual item statistics are presented in Appendix C. The eight items selected to form the final test were those of medium difficulty with high biserial coefficients. Where two items were very similar as to the transformation involved, only one was used. The KR-20 reliability coefficients for the final eight-item test in the two groups were 0.41 (grade 7) and 0.56 (grade 9).

The difficulty of designing a test suitable for grades 7 through 12 necessitated the compromise of aiming at a test suitable for grade 9. In consequence the test is possibly too difficult for grades 7 and 8. In addition the highly verbal nature of this test clashes with the preceding 38 questions. A far less reliable but probably more valid alternative might have been to ask free response questions involving the actual transformations in the volume conservation questions. Another alternative might have consisted of interviews with a subsample of the sample. The aim however was statistical verification of a link between the atomistic schemes and volume conservation so that a test with a known and reasonable reliability was required. Ease of administration and scoring was another consideration.

ADMINISTRATION OF TESTS

The complete schedule of 46 items was administered in the same numerical order to groups of students in normal school classrooms by the same experimenter during school hours in the month of May, 1972. In some cases class units were combined for convenience, but in most cases subjects were tested in normal class units. The schools are isolated from each other by relatively large distances and testing was completed in any one school in the same day, so that communication among subjects was minimised. An exception was in one large high school where grade 9 students were tested one week before the grade

10, 11, and 12 students were tested.

Procedure. Before testing began, the experimenter wrote in large letters on the chalkboard in front of students "There are no tricks" and "A = more, B = less, C = the same." Subjects were told that they were being asked to take part in an experiment to find out more about how people learn things, in particular how they learn about weight and volume. An IBM 5056 answer sheet, a 4" x 6" white ruled file card, and a copy of the printed atomistic schemes test (face down) were given to each subject. Subjects were asked to indicate their name, grade, school, sex, and age to the nearest half year in the appropriate places at the top of the answer sheet.

Subjects were told that no marks would be allotted for the test and that it would not form part of the evaluation of their school progress. They were asked therefore not to copy answers from another subject, nor to communicate with each other. Subjects were told that there would be no tricks, that each question was perfectly straightforward, and that since the test was designed to be used down to grade 7 level and below, some of the questions would be very easy, "even ridiculous". Subjects were told that until further notice, the answer to each question would be one of "more", "less", or "the same." They were told that if they chose "more" for the answer, they should mark A on the answer sheet, for "less" they should mark B, and for "the same" they should mark C. Subjects were asked to stop the experimenter if the pace should be too fast, and were invited to ask questions at any time, as the experimenter wished to make sure that nobody gave the wrong answer through misunderstanding the question. Questions were then

invited before the test began.

Immediately after each of the first three questions, subjects were reminded of the answer code already described (A = more, B = less, C = the same). Throughout the test, any questions were answered immediately, and the asker thanked for his question. If required, an entire test question was repeated. Otherwise the questions were asked in the same way each time. The procedure was interrupted after a previously selected conservation or displacement law question and subjects were asked to write the number of that question on the file card which had been provided. They were then asked to write down the code letter (A, B, or C) of the answer they had just given to that question, and to explain in one or two sentences why they had given that answer. For example, if it were after a weight conservation question, subjects would be told "If you thought the weight was more, say in one or two sentences why you thought it was more. If you thought the weight was less, say in one or two sentences why you thought it was less. If you thought the weight was the same, say in one or two sentences why you thought it was the same." A different question was selected for each group, and in this way, a sampling of subjects' reasons for their response choice was obtained for most questions.

TREATMENT OF THE DATA

The response sheets were machine scored and each subjects' response choice for each question was recorded on IBM punch cards, one

per subject. A subject's age, sex, and grade were coded into an identification number. On another set of punch cards, one for each subject, were recorded a score for each item (1 for correct, 0 for incorrect), a subtotal for the 18 weight conservation questions, a subtotal for each of the four sets of three volume conservation questions (either verbal or displacement questions for either plastic-body or rigid-body transformations), a subtotal for the eight displacement law questions, and a subtotal for the eight-item atomistic schemes test. Decile ranks for the Alberta Department of Education science achievement test and for the SCAT test and stanines for the verbal and quantitative subtotals of the SCAT test were recorded on the cards of the grade 9 subjects for whom such results were available.

Scores were then tabulated and processed to generate the following:

1. Contingency tables (6 x 2) of item response (scored 0, 1) against grade 7 through 12, controlled for sex of subject.

2. Contingency tables (3 x 2) of item response against grade 7 through 9, and against grade 10 through 12, controlled for sex of subject.

3. Chi-squares and contingency coefficients associated with the contingency tables in 1 and 2 above.

4. Contingency tables (2 x 2) of item response against sex of subject, controlled for grade.

5. Chi-squares and phi-coefficients associated with the tables in 4 above.

6. Product-moment coefficients of correlation among all items

and subtotals as described above (p. 81), and for grade 9 subjects Alberta Department of Education tests.

7. Analysis of variance in boys' and girls' scores on SCAT verbal and quantitative subtotals.

8. Mean scores by item (i.e. per cent correct response) and KR-20 coefficients for weight conservation test (18 items), volume conservation test (12 items), displacement law test (8 items), and atomistic schemes test (8 items), controlled for sex and grade in each case.

SUMMARY

The sample consisted of all students in grades 7 through 12 in all schools under the jurisdiction of the County of Wetaskiwin No. 10 who were present in school on the days of testing--a total of 906 subjects. According to tests administered previously by the Alberta Department of Education, there were no significant differences between the distributions of scores on science achievement or scholastic aptitude (SCAT) tests among the grade 9 students in the sample and grade 9 students in the province of Alberta as a whole.

The following were tested in a fixed standard procedure of oral questions with demonstrations:

(a) Weight conservation in simple and complex transformations,

(b) Volume conservation in rigid-body and plastic-body transformations, with both verbal and displacement questions,

(c) Understanding of the displacement law.

Atomistic schemes of compression and dilatation were tested in an eight-item multiple-choice written test. Throughout all parts of the testing procedure subjects recorded their own responses on supplied answer sheets. Reasons for responses to conservation and displacement law tests were sampled by asking each group to write a short reason for the response to selected questions. Administration was to normal class groups or combinations of class groups in normal school periods towards the end of the school year. Subjects' scores were recorded for each item, various subtotals were generated for each subject, and the data analysed for groups of subjects according to grade and sex to test the hypotheses forwarded in Chapter I. The results of this analysis are reported in Chapter IV.

CHAPTER IV

RESULTS

The hypotheses raised in Chapter I will now be restated in turn together with a report of the corresponding results. Although conclusions will be reached with regard to each hypothesis, a more extensive discussion of the results of the experiment will follow in Chapter V.

WEIGHT CONSERVATION

The hypotheses to be considered in connection with the weight conservation test are:

1.1 There are students in secondary school grades who may be classed as nonconservers of weight in simple transformations like change of shape.

1.2 There are students in secondary school grades who may be classed as conservers of weight in simple transformations but who do not conserve weight in complex transformations like change of state.

1.3 The incidence of nonconservation of weight in both simple and complex transformations decreases with grade.

The percentage of conservers in each of the weight conservation questions are summarised in Table 6 by grade and sex.[1]

TABLE 6

PER CENT OF CONSERVERS IN WEIGHT CONSERVATION QUESTIONS

Question	Sex	7	8	9	10	11	12
1s	M	87	95	99	99	100	100
	(F)	(91)	(95)	(91)	(95)	(100)	(95)
2s	M	85	95	100	99	100	100
	(F)	(93)	(98)	(95)	(98)	(100)	(98)
3s	M	77	89	96	94	98	100
	(F)	(78)	(88)	(91)	(90)	(98)	(95)
4s	M	83	82	90	95	86	94
	(F)	(75)	(73)	(79)	(88)	(98)	(95)
5s	M	84	91	97	92	98	100
	(F)	(78)	(94)	(94)	(95)	(98)	(90)
6s	M	46	63	75	85	93	91
	(F)	(38)	(44)	(59)	(75)	(79)	(76)
7s	M	42	67	64	83	89	78
	(F)	(37)	(41)	(41)	(63)	(75)	(78)
8s	M	85	84	94	92	98	97
	(F)	(85)	(82)	(88)	(83)	(91)	(95)
9s	M	75	83	92	95	98	97
	(F)	(76)	(76)	(81)	(93)	(95)	(90)
10s	M	70	88	93	89	98	100
	(F)	(74)	(75)	(80)	(90)	(91)	(81)
11	M	94	98	99	91	100	100
	(F)	(97)	(98)	(96)	(95)	(100)	(90)
12	M	50	63	67	80	77	97
	(F)	(41)	(44)	(65)	(73)	(61)	(76)
13	M	43	50	52	79	68	97
	(F)	(43)	(37)	(46)	(55)	(37)	(44)
14	M	18	40	43	65	57	78
	(F)	(23)	(23)	(38)	(43)	(28)	(44)
15	M	24	39	38	55	57	81
	(F)	(20)	(25)	(43)	(58)	(35)	(32)
16	M	72	78	73	80	89	94
	(F)	(63)	(65)	(69)	(80)	(86)	(78)
17	M	71	74	80	82	82	88
	(F)	(70)	(80)	(79)	(80)	(84)	(71)
18	M	94	97	97	95	96	100
	(F)	(92)	(98)	(95)	(98)	(98)	(93)
N	M	107	120	101	65	44	32
	(F)	(99)	(108)	(106)	(40)	(43)	(41)

Simple Transformations

As would be expected, the frequencies of nonconservation for the simple transformations (marked s in Table 6) are very low in some cases. This makes determination of their difference from zero difficult. Recall from Chapter III (p. 73) that questions 11 and 18 were obvious. It has to be allowed that any subject who answered one of these questions incorrectly was momentarily inattentive, marked his answer sheet other than where he intended, etc. Any apparent proportion of nonconservers in a given question has to be reduced by the proportion of incorrect responses to these obvious questions.

To determine whether the proportion of nonconservation in any given question was in fact nonzero, (taking into account the level of incorrect response through inattention, etc.) the following null hypotheses were tested with a rejection level of 0.05:

a. For subjects of the same sex in the same grade, there is no difference between the proportions of correct response to questions 11 and 18 (the obvious questions).

b. For subjects of the same sex in the same grade, the proportion of conservers in a given question is not less than the proportion of correct response to question 11 or question 18 (whichever is the lower). Fisher's z test for the significance of the difference between independent proportions (Ferguson, 1966, pp. 176-178) was used in both cases. It was assumed that the level of incorrect response through inattention etc. remains constant from question to question.

The questions which were found to have nonzero proportions of nonconservers are listed in Table 7. The list includes almost all questions in the lower grades. Confirmation that a nonconservation frequency is nonzero can be obtained by examining trends by grade.[2] It may be inferred that in lower grades, the frequencies of nonconservers which display a negative trend by grade must be nonzero, because it is not possible for frequencies to decrease below zero. Questions for which a negative trend by grade was found for nonconservation are marked with an asterisk in Table 7. Assuming that questions 1 (sectioning of clay cylinder), 2 (clay prism to ring), 3 (metal clamp on stand), and 5 (inversion of flask) test for conservation in a classical Piagetian sense, then about eight to sixteen per cent of boys and about twenty per cent of girls in grade 7 may be classed as nonconservers of weight. These proportions diminish to an extent indistinguishable from zero by grade 9.

Complex Transformations

Although nearly all subjects were found to conserve weight in the simple transformations like sectioning of clay (question 1), it can be seen from Table 6 that from one- to four-fifths of subjects are prepared to accept that the weight might change in the more complex transformations in questions 12 through 15. Of grade 12 boys, 17 per cent believe that the weight of a metal bar changes when it is heated (question 12), while 82 per cent of grade 7 boys believe that the weight of a sealed can containing a small amount of gasoline changes when the gasoline evaporates (question 14). As shown in Table 8, in

TABLE 7

LIST OF WEIGHT-CONSERVATION QUESTIONS FOR WHICH THE PROPORTIONS OF NONCONSERVERS IS GREATER THAN ZERO

Boys Grade				Girls Grade			
7	8	9	10-12	7	8	9	10-12
* 1							
* 2							
* 3	3			* 3	3		
4	4	4		4	4	4	
* 5	5			* 5			
* 6	6	6	6	* 6	6	6	6
* 7	7	7	7	7	7	7	7
* 8	8			8	8	8	8
* 9	9			9	9	9	
*10	10		10**	10	10	10	10
*12	12	12	12**	*12	12	12	12
13	13	13	13**	13	13	13	13
*14	14	14	14	*14	14	14	14
*15	15	15	15**	*15	15	15	15*
16	16	16	16	16	16	16	16
17	17	17	17	17	17	17	17

* = significant positive contingency coefficient ($p < 0.05$) of correlation of question response with grade, junior high.

** = significant positive contingency coefficient ($p < 0.05$) of correlation of question response with grade, senior high.

TABLE 8

SIGNIFICANT CHI-SQUARES FOR SEX DIFFERENCE IN

WEIGHT CONSERVATION QUESTIONS (df = 1)

	Grade					
Question	7	8	9	10	11	12
1			7.33*			
2						
3						
4			4.66			
5						
6		8.23*	7.39*			
7		15.40*	11.7*	5.63	6.80*	
8						
9			5.30			
10		5.91	7.34*			5.15
11						
12		7.46*				4.80
13		3.88		6.43	8.37*	22.9*
14		7.42*		4.92	7.44*	8.70*
15		5.20			4.21	17.7*
16		4.49				
17						
18						

* = $p < 0.01$
The other chi-squares have $0.05 > p > 0.01$.

most cases above grade 7 significantly more boys than girls respond correctly to the complex transformation questions 12 through 15. Possible explanations for failure to conserve in the complex transformations will be discussed in Chapter V.

Trends by Grade

To detect trends by grade in item response, chi-squares and contingency coefficients were computed for contingency tables having item response as one variable, grade as the other. Table 9 presents all such chi-squares which are significant at the 0.05 level, together with the associated contingency coefficients. If grade is allowed to vary from 7 through 12, the chi-squares of the associated 6 x 2 contingency tables are as a rule highly significant. It may be that the higher grades represent a somewhat select group, since students who drop out of school are usually those of lesser ability or achievement. The school leaving age is 16, precluding students dropping out before grade 9. Accordingly the chi-squares and contingency coefficients were recomputed for junior and senior high grades separately in 3 x 2 contingency tables, and these statistics also appear in Table 9. Significant chi-squares are found for most questions in the junior high school, but only for the complex transformation questions in the senior high school.

A nonsignificant chi-square indicates that the corresponding item has a difficulty level independent of grade level. This may mean that development of the conservation ability for the particular transformation does not occur in the period tested (grades 7 to 9 or

TABLE 9

SIGNIFICANT CHI-SQUARES AND CONTINGENCY COEFFICIENTS FOR TRENDS BY GRADE IN PROPORTION OF CONSERVERS OF WEIGHT

Question	Grades 7-12 (*df* = 5) χ^2 M	(F)	C M	(F)	Grades 7-9 (*df* = 2) χ^2 M	(F)	C M	(F)	Grades 10-12 (*df* = 2) χ^2 M	(F)	C M	(F)
1	27.8		.24		13.3		.20					
2	36.8		.27		19.5		.24					
3	35.3	(16.5)	.26	(.19)	18.2	(7.5)	.23	(.15)				
4	11.2	(21.0)	.15	(.21)								
5	19.5	(26.2)	.20	(.24)	10.1	(19.3)	.17	(.24)				
6	60.7	(40.9)	.34	(.29)	20.4	(9.1)	.24	(.17)				
7	49.8	(32.4)	.31	(.26)	16.5		.22					
8	14.8		.17									
9	31.4	(15.4)	.25	(.18)	11.2		.18					
10	41.7	(29.1)	.29	(.25)	22.1		.25		6.0		.20	
11	14.8		.18						7.3		.22	
12	55.7	(14.0)	.27	(.18)	7.4	(13.9)	.15	(.21)				
13	48.7	(25.0)	.31	(.24)					9.4		.25	
14	60.2	(12.5)	.34	(.17)	17.9	(7.3)	.23	(.15)				
15	43.9		.29		6.5	(13.8)	.14	(.21)	6.7	(6.6)	.21	(.22)
16	11.9		.16									
17												
18												

Note. Probability table for chi-square:

p	0.05	0.01	0.001
df = 2	5.99	9.21	13.82
df = 5	11.07	15.09	20.52

10 to 12). If development does not occur it could be that the ability is already fully developed at the beginning of the period. Alternatively, it could be that development of the ability has to await development in other areas during the period. Another interpretation, of course, is that subjects in all grades misunderstand the question.

Conclusions

The results tend to support hypotheses 1.1, 1.2, and 1.3. About eight to sixteen per cent of boys and about twenty per cent of girls in grade 7 may be classed as nonconservers of weight. These proportions diminish to an extent indistinguishable from zero by grade 9. In complex transformations like heating a metal bar or melting ice, more than half of grade 7 students do not conserve weight. By grade 12 most subjects conserve weight in simple and complex transformations.

DISPLACEMENT LAW

The criterion for understanding of the displacement law was set at a score of five or more on the eight-item displacement law test. To have scored less than five a subject must feel that the weight of the immersed object or some animistic force determines the rise in level of the liquid.[3] This is a very liberal criterion especially in view of the high KR-20 reliability coefficients of the test as a whole. These coefficients lie between 0.62 (grade 8 girls) and 0.76 (senior high girls).

The hypotheses to be considered in connection with the displacement law test are:

2.1 There are significant proportions of students in secondary school grades who do not understand the displacement law.

2.2 Higher proportions of girls than boys do not understand the displacement law.

Proportions of subjects of the same sex in the same grade who do not understand the law, presented in Table 10, are remarkably high except for boys in senior high grades, ranging from 20 per cent of grade 9 boys to 73 per cent of grade 8 girls. Even more remarkable is the clear-cut sex difference in understanding of the law. Table 11 presents chi-squares of 2 x 2 contingency tables with sex as one variable, displacement law understanding as the other. The lowest of these chi-squares has a probability of less than 2×10^{-5} ($\underline{df} = 1$), indicating that the disparity between boys' and girls' performances on the displacement law test is unlikely to be a chance result.

Conclusions

The results support hypotheses 2.1 and 2.2. On the basis of the apparently liberal criterion adopted, 43 per cent of grade 7 boys and 73 per cent of grade 7 girls do not understand the law. By grade 12, virtually all boys but only 51 per cent of girls understand the law of displacement of fluids.

TABLE 10

PER CENT OF SUBJECTS WHO DO NOT UNDERSTAND

THE DISPLACEMENT LAW

Grade	Boys	Girls
7	42	73
8	24	67
9	20	61
10	6	52
11	16	51
12	3	49

TABLE 11

CONTINGENCY TABLES OF DISPLACEMENT LAW AGAINST

SEX OF SUBJECT (df = 1)

	Displacement Law (frequencies) 0-4	5-8	χ^2
	Grade 7		
Boys	46	61	
Girls	73	26	29.9
	Grade 8		
Boys	26	94	
Girls	73	35	35.8
	Grade 9		
Boys	20	81	
Girls	65	41	37.0
	Grade 10		
Boys	4	61	
Girls	21	19	28.5
	Grade 11		
Boys	7	37	
Girls	22	21	25.2
	Grade 12		
Boys	1	31	
Girls	20	21	18.6 ($p < 2 \times 10^{-5}$)

VOLUME CONSERVATION

The hypotheses to be considered in connection with the volume conservation test are:

3.1 There are significantly large proportions of students in secondary school grades who may be classed as nonconservers of volume.

3.2 Higher proportions of boys than girls conserve volume.

3.3 The proportion of nonconservers of volume in rigid-body transformations (involving only simple sectioning or relative displacement of separate parts) is lower than the proportion of nonconservers of volume in plastic-body transformations.

3.4 Higher proportions of conservers of volume are found in tests involving verbal questions only, than are found in tests involving displacement of water only, because of subjects who believe weight causes displacement and thereby conserve weight, not volume, in the displacement question.

Table 12 shows, for subjects of the same sex in the same grade, the per cent of correct response to each volume question. Verbal questions are odd-numbered. The corresponding displacement question for a verbal question is the succeeding even-numbered question. The first three pairs of questions (19-20, 21-22, 23-24) represent the rigid-body transformations, the latter three pairs (25-26, 27-28, 29-30) represent the plastic-body transformations. The transformations are described on pp. 75-76.

TABLE 12

PER CENT OF CONSERVERS IN VOLUME CONSERVATION QUESTIONS

Question	Sex	7	8	9	10	11	12
19	M	70	77	86	94	91	97
	(F)	(67)	(67)	(79)	(83)	(84)	(93)
20	M	67	83	85	92	86	94
	(F)	(62)	(71)	(71)	(85)	(81)	(78)
21	M	37	53	56	65	68	84
	(F)	(31)	(30)	(35)	(28)	(44)	(46)
22	M	55	75	77	83	73	88
	(F)	(55)	(61)	(70)	(70)	(77)	(66)
23	M	66	79	84	80	84	88
	(F)	(61)	(64)	(81)	(70)	(77)	(78)
24	M	75	88	89	97	91	100
	(F)	(83)	(87)	(83)	(93)	(88)	(90)
25	M	56	79	83	89	91	94
	(F)	(56)	(62)	(71)	(70)	(77)	(71)
26	M	63	85	90	89	96	100
	(F)	(65)	(78)	(75)	(78)	(88)	(88)
27	M	59	76	81	86	89	97
	(F)	(52)	(56)	(61)	(65)	(72)	(81)
28	M	60	81	89	94	91	100
	(F)	(65)	(69)	(72)	(88)	(79)	(85)
29	M	47	73	81	85	82	94
	(F)	(46)	(47)	(60)	(60)	(67)	(73)
30	M	56	82	85	91	82	100
	(F)	(57)	(63)	(69)	(73)	(79)	(76)

Level of Nonconservation and Sex Differences

Table 13 shows the per cent of volume conservation in the verbal question for the ball-sausage transformation (question 25) compared with that found by Elkind (1961c). The ball-sausage transformation was used by Elkind, but he required a subject to predict, judge, and explain correctly the conservation of volume. In the present study, subjects were required only to judge whether volume remained unchanged in the various transformations. It can be seen that the percentages found here exceed those of Elkind in every grade, possibly because of the lesser criterion. The sex difference Elkind discovered occurs here also. Only in grade 7 are there any cases where the proportion of volume conservers is not lower for girls than it is for boys. Chi-squares of contingency tables of sex against response to volume conservation questions are shown in Table 14, and are significant at the 0.05 level in almost every case above grade 7, again indicating that the disparity between girls' and boys' performance on volume conservation testing is unlikely to be a chance result. The results therefore support hypotheses 3.1 and 3.2.

Methodology of Volume Conservation Testing

The methodology of volume conservation testing has been discussed in Chapter I (pp. 7-9) and again in Chapter II (pp. 27-34). It was hypothesised that (a) the kind of transformation, and (b) the kind of question would affect the level of conservation detected. The volume conservation test was designed to include two kinds of transformation

TABLE 13

PER CENT OF VOLUME CONSERVATION IN BALL-SAUSAGE TRANSFORMATION (QUESTION 25) COMPARED WITH PER CENT OF VOLUME CONSERVERS FOUND BY ELKIND (1961c)

Grade	Elkind		Present Experiment	
	M	(F)	M	(F)
7	38	(26)	56	(56)
8	43	(29)	79	(62)
9	68	(40)	83	(71)
10	58	(39)	89	(70)
11	72	(58)	96	(88)
12	79	(68)	100	(88)

TABLE 14

SIGNIFICANT CHI-SQUARES FOR SEX DIFFERENCE IN VOLUME

CONSERVATION QUESTIONS (df = 1)

Question	Grade 7	Grade 8	Grade 9	Grade 10-12
19				3.93
20		4.74	6.20	5.26
21		13.1*	9.67*	25.4*
22		5.08		
23		6.57*		
24				
25		8.11*	4.48	15.3*
26			8.54*	6.40*
27		10.1*	9.91*	12.4*
28		3.98	9.87*	7.32*
29		16.3*	10.8*	12.6*
30		10.0*	7.70*	9.70*

* = $p < 0.01$ ($\chi^2 > 6.64$)
The other chi-squares have $0.05 > p > 0.01$ ($3.84 < \chi^2 < 6.64$)

in two kinds of question. Comparisons of volume conservation proportions will now be made on the basis of each of these two variables in turn.

Rigid-Body vs. Plastic-Body Transformations. By a rigid-body transformation is meant one which involves either sectioning alone, or relative displacement of separate parts. Question pairs involving rigid-body transformations are 19-20 (unfolding of hinged wooden blocks), 21-22 (unfolding of rolled lead strip), and 23-24 (splitting of clay ball). Question pairs involving plastic-body transformations are 25-26 (ball-sausage), 27-28 (ball-pancake), and 29-30 (metal melting and recasting). Subjects who correctly answered one or none of the verbal questions 19, 21, or 23 were classed as nonconservers of volume for rigid-body transformations, and subjects who correctly answered one or none of the verbal questions 25, 27, or 29 were classed as nonconservers for plastic-body transformations. The choice of the verbal questions to form the criterion is consistent with the implication in hypothesis (3.3) that the displacement question alone gives an inflated proportion of conservers.

The requirement is to test the difference between the proportions of rigid-body-transformation conservers and plastic-body-transformation conservers. These proportions must be correlated[4] therefore a $\underline{z}$ - test test for significance of difference between correlated proportions may be used (Ferguson, 1966, pp. 178-181). The results, presented in Table 15 are inconclusive. For senior high and grade 9 boys, cell frequencies are too low for the corresponding $\underline{z}$ to be interpretable. Proportions of conservers in rigid-body transformations

TABLE 15

SIGNIFICANCE OF DIFFERENCES BETWEEN PROPORTIONS OF VOLUME CONSERVERS IN RIGID-BODY AND PLASTIC-BODY TRANSFORMATIONS (VERBAL QUESTION)*

Group	A	D	*z*	*p*
Grade 7 Boys	21	7	2.64	0.01
Grade 7 Girls	11	11	0.19	0.85
Grade 8 Boys	5	14	-2.07	0.04
Grade 8 Girls	18	11	1.30	0.19
Grade 9 Boys	5	6	---	--
Grade 9 Girls	19	7	2.38	0.02
Grade 10-12 Boys	4	12	---	--
Grade 10-12 Girls	18	14	0.71	0.48

* Ferguson (1966, pp. 178-181)

are found to be significantly higher than in plastic-body transformations for grade 7 boys and grade 9 girls, but not for grade 7, 8, or senior high girls. A significant difference is found for grade 8 boys, but in this case the plastic-body transformations were <u>less</u> difficult.

More conclusive results are obtained if question 21 (unfolding of rolled lead strip) is not classed as a rigid-body transformation. Inspection of Table 12 indicates that question 21 is considerably more difficult than any of the other questions. The question could have been interpreted by many subjects as referring to the peripherally enclosed space of the lead foil roll, which actually does decrease on unfolding. There were spaces between the folded layers since perfectly flat folding was not possible. Reference to Figure 3 in Appendix A (p. 163) will make this clear. By contrast, the corresponding displacement question (22) shows a proportion of conservers comparable with the other questions. Question 21 therefore appears to be testing something different than the other questions.

In Table 16 the differences between the verbal questions taken two by two are presented. Results are shown for junior high school only, but similar results are obtained if each grade is taken separately. The order of difficulty of the questions is clearly

19 23 25 27 29 21.

In addition, there is no significant difference between the rigid-body transformations 19 (unfolding of hinged blocks) and 23 (splitting of clay ball). A reasonable conclusion however would be that these two questions represent close points on a continuum of difficulty, rather than members of the same class in a dichotomy (according to type of

TABLE 16

UNIT-NORMAL-CURVE DEVIATES FOR DIFFERENCES AMONG VERBAL QUESTIONS IN VOLUME CONSERVATION TEST (FERGUSON, 1966, pp. 178-181)

Ques-tion	Question				
	M (F)	M (F)	M (F)	M (F)	M (F)
23	0.35 (0.83)				
25	1.67*(2.68*)	1.30 (1.88*)			
27	1.96*(4.50*)	1.78*(3.72*)	0.49 (2.16*)		
29	3.62*(5.70*)	3.40*(5.25*)	2.40*(4.05*)	2.06*(1.83*)	
21	8.30*(10.1*)	8.20*(9.60*)	8.10*(8.65*)	7.36*(7.05)	6.05*(5.85*)

* = $p < 0.05$ (One-tailed test)

transformation). Assuming that question 21 (unfolding of rolled lead strip) is not anomalous, the difficulty order could be explained in terms of the relative magnitudes of increase in surface area. This would be consistent with the idea that a prerequisite to volume conservation is correct relationship of boundary surfaces to volume. Thus the evidence does not support hypothesis 3.2.

Verbal vs. Displacement Question. For each transformation the volume conservation question was asked twice--first verbally, then in terms of displacement level alone. The verbal questions are odd-numbered, the displacement questions even-numbered. The actual methods of asking the questions were described in Chapter III (pp. 74 75). Briefly, the verbal question was asked in terms of volume or "room taken up", while the displacement question was asked solely in terms of water levels with no mention of volume or room occupied.

As would be expected, response to a verbal question correlates with response to the corresponding displacement question. Phi-coefficients are presented in Table 17. This follows since few who answer the verbal question correctly answer the displacement question incorrectly. The actual response patterns for the two questions will be examined presently.

A z-test for significance of difference between correlated proportions (Ferguson, 1966, pp. 178-181) was used to test the significance of difference between the proportions of conservers on each type of question. The results are presented in Table 18. The null hypothesis of no difference is rejected except for question pair 19-20 (unfolding of hinged wooden blocks). The difference is very great

TABLE 17

PHI-COEFFICIENTS OF CORRELATION BETWEEN VERBAL AND DISPLACEMENT VOLUME CONSERVATION QUESTIONS

Question pair	Grade 7		8		9		10-12	
	M	(F)	M	(F)	M	(F)	M	(F)
19-20	.27*	(.13)	.33*	(.24*)	.71*	(.38*)	.12	(.17)
21-22	.43*	(.24*)	.38*	(.18)	.19	(.22*)	.39*	(.30*)
23-24	.17	(.02)	.64*	(.34*)	.37*	(.10)	.37*	(.25*)
25-26	.52*	(.39*)	.47*	(.27*)	.55*	(.29*)	.52*	(.34*)
27-28	.40*	(.33*)	.61*	(.37*)	.48*	(.53*)	.31*	(.42*)
29-30	.43*	(.38*)	.54*	(.38*)	.58*	(.41*)	.41*	(.40*)
N	107	(99)	120	(108)	101	(106)	141	(124)

* $p < 0.05$

TABLE 18

FREQUENCIES OF VOLUME CONSERVERS FOR VERBAL AND DISPLACEMENT QUESTIONS, AND z-TEST FOR SIGNIFICANCE OF DIFFERENCE BETWEEN THE CORRESPONDING PROPORTIONS

Question Pair	Verbal Question			Displacement Question			z		
	M	(F)	M&F	M	(F)	M&F	M	F	(M&F)
				Junior High (Grades 7-9)					
19-20	254	(243)	497	258	(259)	515	0.49	(1.23)	1.58
21-22	189	(101)	290	226	(195)	421	6.26	(8.10)	10.2
23-24	246	(215)	461	271	(264)	535	2.48	(5.25)	6.02
25-26	240	(197)	437	261	(226)	487	2.83	(3.00)	4.10
27-28	236	(177)	413	251	(216)	467	1.94	(4.13)	4.40
29-30	221	(166)	387	238	(204)	442	2.90	(4.05)	4.86
N	328	(313)	651	328	(313)	651			
				Senior High (Grades 10-12)					
19-20	132	(107)	239	107	(101)	200	-0.94	(-1.13)	-1.46
21-22	99	(49)	148	114	(88)	202	2.60	(5.57)	4.00
23-24	117	(93)	210	135	(112)	247	4.02	(3.53)	5.30
25-26	128	(90)	218	132	(105)	237	1.26	(2.78)	3.08
27-28	126	(90)	216	133	(104)	237	1.81	(2.74)	3.28
29-30	121	(83)	200	127	(94)	221	1.41	(1.98)	2.44
N	141	(124)	265	141	(124)	265			

For $z > 1.96$, $p > 0.05$.
For $z > 2.56$, $p > 0.01$.

($\underline{z}$ = 10.2, $p > 0.01$) for question pair 21-22 (unfolding of rolled lead strip).

Apparently the perceptual aspects of the transformation in question 19 (hinged blocks) are not particularly misleading, and nearly all subjects conserve volume. On the other hand in the corresponding displacement question (20), the wooden blocks have to be pushed under the water, and perhaps this makes the situation a little more misleading. For instance, a grade 9 subject writes in explanation "I'll (sic) rise more because the stick has to be pushed into the water before it becomes completely immersed thus forcing it to rise more." The apparently anomalous difficulty of question 21 (lead strip) has already been mentioned (p. 103), thus the difference between the displacement and verbal questions is probably spuriously accentuated in question pair 21-22 and spuriously reduced in question pair 19-20. These effects tend to cancel each other in the analysis which follows, but it would not be unjustified to omit both pairs from further consideration.

Now that a difference has been established between the verbal and displacement questions, the source of the difference may be investigated. The hypothesis to be considered is that the difference is caused by subjects who believe weight causes displacement and thus conserve weight, not volume, in the displacement question (hypothesis 3.3). In fact there are not just two kinds of subject--conservers and nonconservers of volume--but potentially eight. This is because a subject may or may not conserve on the verbal question, may or may not conserve in the displacement question, and may or may not believe weight

causes displacement.

Let a subject's set of responses be described by a combination of the following statements:

v = S correctly answers verbal question,

d = S correctly answers displacement question, and

l = S correctly understands displacement law.

Let $\bar{v}$, $\bar{d}$, and $\bar{l}$ represent negations of these statements ($\bar{l}$ subjects think weight causes displacement).

Then the set of eight conjunctions (v.d.l, $\bar{v}$.d.l, v.$\bar{d}$.l, $\bar{v}$.$\bar{d}$.l, v.d.$\bar{l}$, $\bar{v}$.d.$\bar{l}$, v.$\bar{d}$.$\bar{l}$, and $\bar{v}$.$\bar{d}$.$\bar{l}$) includes all possible patterns of response. Meaning can be attached to each of these response patterns as follows:

The case (v.d.l) represents what could be called "complete" conservation of volume. Only (v.d.l) subjects would meet Elkind's (1961a) criterion of prediction, judgement, and explanation. The cases ($\bar{v}$.d.l), (v.$\bar{d}$.l), and (v.$\bar{d}$.$\bar{l}$) appear to represent anomalous cases. The first two represent contradictory response, the subject conserving on the verbal question but not on the displacement question, or vice versa. The third--(v.$\bar{d}$.$\bar{l}$)--would represent conservation of volume but not of weight, an inversion of the invariable order of quantity concept acquisition. The cases (v.d.$\bar{l}$) and ($\bar{v}$.$\bar{d}$.l) represent volume conservation in the absence of the displacement law and vice versa. The case ($\bar{v}$.d.$\bar{l}$) is that in which apparent volume conservation in the displacement law is actually weight conservation. This is the case hypothesised to account for the difference between verbal and displacement questions. Finally, the case ($\bar{v}$.$\bar{d}$.$\bar{l}$) would represent failure to conserve either volume or

weight. These interpretations can be summarised as follows:

$v.d.l$ = complete volume conservation,

$\overline{v}.d.l$ = inconsistent response,

$v.\overline{d}.l$ = inconsistent response,

$\overline{v}.\overline{d}.l$ = displacement law without volume conservation,

$v.d.\overline{l}$ = volume conservation without displacement law,

$\overline{v}.d.\overline{l}$ = weight conservation in displacement question,

$v.\overline{d}.\overline{l}$ = volume conservation, weight nonconservation, (reversal of invariable order), and

$\overline{v}.\overline{d}.\overline{l}$ = conservation of neither weight nor volume.

Thus it is expected that ($\overline{v}.d.l$), ($v.\overline{d}.l$), and ($v.\overline{d}.\overline{l}$) have frequencies which tend to zero, since they represent apparently anomalous cases, so that the difference in frequencies of verbal and displacement conservers is made up of ($\overline{v}.d.\overline{l}$) cases.[5]

Table 19 presents the actual frequencies of each response pattern for subjects of the same sex in each of the following groups: grade 7, grade 8, grade 9, junior high (grades 7-9), and senior high (grades 10-12). The criterion for understanding of the displacement law used in calculating frequencies for this table was a fairly specific one, based on response to the displacement law questions 32, 33, and 36.[6] An incorrect response to any one of these questions indicates a belief that the weight of the immersed object determines the new level of liquid on immersion. Subjects who responded correctly to at least two of these items were classed as understanding the displacement law. Since there are eight possible categories for the data, *N* should be fairly large, and for this reason, most of the remainder of this analysis is

TABLE 19

FREQUENCIES OF RESPONSE PATTERN FOR VERBAL QUESTION, DISPLACEMENT QUESTION, AND DISPLACEMENT LAW

Question Pair	Group 7 M	7 (F)	8 M	8 (F)	9 M	9 (F)	Junior High M	Junior High (F)	Senior High M	Senior High (F)
					I: Response Pattern (v.d.1)					
19-20	44	(13)	71	(19)	66	(23)	181	(55)	78	(33)
21-22	29	(8)	53	(15)	41	(14)	123	(37)	60	(23)
23-24	44	(15)	77	(26)	62	(28)	183	(69)	73	(36)
25-26	42	(13)	76	(23)	67	(22)	185	(58)	78	(31)
27-38	36	(13)	66	(17)	64	(20)	166	(50)	78	(32)
29-30	34	(10)	70	(16)	63	(23)	167	(49)	73	(32)
N	107	(99)	120	(108)	101	(106)	328	(315)	141	(124)
					II: Response Pattern (v.$\bar{d}$.1)					
19-20	7	(5)	5	(4)	4	(2)	16	(11)	5	(5)
21-22	4	(4)	5	(2)	7	(4)	16	(10)	6	(2)
23-24	7	(2)	1	(0)	5	(2)	13	(4)	0	(1)
25-26	4	(4)	4	(1)	2	(2)	10	(7)	0	(3)
27-28	9	(0)	5	(1)	1	(2)	15	(3)	0	(1)
29-30	4	(1)	1	(3)	2	(3)	7	(5)	2	(2)
					III: Response Pattern ($\bar{v}$.d.1)					
19-20	8	(3)	9	(8)	2	(5)	19	(16)	3	(3)
21-22	12	(5)	21	(10)	22	(10)	55	(25)	17	(11)
23-24	12	(3)	3	(5)	5	(0)	20	(8)	12	(3)
25-26	7	(1)	4	(4)	2	(3)	13	(8)	6	(6)
27-28	4	(3)	7	(6)	6	(3)	17	(12)	7	(4)
29-30	8	(5)	10	(5)	4	(3)	22	(13)	8	(3)

TABLE 19 (Continued)

FREQUENCIES OF RESPONSE PATTERN FOR VERBAL QUESTION DISPLACEMENT QUESTION, AND DISPLACEMENT LAW

Question Pair	Group 7 M	7 (F)	8 M	8 (F)	9 M	9 (F)	Junior High M	Junior High (F)	Senior High M	Senior High (F)
IV: Response Pattern $(\bar{v}.\bar{d}.1)$										
19-20	6	(0)	5	(1)	4	(2)	15	(3)	1	(2)
21-22	20	(8)	11	(5)	6	(4)	37	(17)	11	(10)
23-24	2	(1)	9	(1)	4	(2)	15	(4)	4	(2)
25-26	12	(5)	6	(4)	5	(5)	23	(14)	2	(3)
27-28	16	(3)	12	(8)	5	(7)	33	(18)	2	(5)
29-30	19	(3)	9	(8)	7	(3)	35	(14)	6	(5)
V: Response Pattern $(v.d.\bar{1})$										
19-20	13	(31)	12	(38)	17	(44)	42	(113)	11	(49)
21-22	4	(14)	5	(9)	7	(17)	16	(40)	5	(15)
23-24	13	(35)	17	(40)	18	(45)	48	(120)	13	(43)
25-26	10	(32)	13	(35)	15	(40)	38	(107)	14	(44)
27-28	12	(29)	20	(34)	15	(39)	47	(102)	12	(43)
29-30	6	(25)	13	(26)	15	(31)	34	(82)	12	(32)
VI: Response Pattern $(v.\bar{d}.\bar{1})$										
19-20	11	(18)	4	(11)	0	(15)	15	(44)	6	(12)
21-22	3	(8)	1	(6)	2	(2)	6	(16)	3	(4)
23-24	7	(8)	0	(3)	0	(11)	7	(22)	1	(4)
25-26	5	(8)	2	(8)	0	(11)	7	(27)	3	(4)
27-28	6	(8)	0	(8)	2	(4)	8	(20)	4	(5)
29-30	7	(7)	4	(6)	2	(7)	13	(20)	4	(8)
VII: Response Pattern $(\bar{v}.d.\bar{1})$										
19-20	7	(14)	8	(12)	1	(3)	16	(29)	4	(8)
21-22	13	(28)	11	(32)	8	(33)	32	(93)	7	(34)

TABLE 19 (Continued)

FREQUENCIES OF RESPONSE PATTERN FOR VERBAL QUESTION DISPLACEMENT QUESTION, AND DISPLACEMENT LAW

Question	Group									
	7		8		9		Junior High		Senior High	
Pair	M	(F)	M	(F)	M	(F)	M	(F)	M	(F)
23-24	11	(29)	9	(23)	5	(15)	25	(67)	7	(21)
25-26	9	(17)	9	(22)	7	(14)	25	(53)	1	(16)
27-28	12	(20)	4	(18)	5	(14)	21	(72)	4	(16)
29-30	12	(16)	5	(21)	4	(16)	21	(53)	4	(18)
VIII: Response Pattern $(\bar{v}.\bar{d}.\bar{l})$										
19-20	11	(14)	6	(15)	7	(12)	24	(41)	1	(4)
21-22	22	(27)	13	(29)	8	(22)	43	(78)	7	(20)
23-24	11	(5)	4	(10)	2	(3)	17	(18)	1	(5)
25-26	18	(20)	6	(11)	3	(9)	27	(40)	4	(9)
27-28	12	(20)	6	(16)	3	(17)	21	(53)	2	(9)
29-30	17	(29)	8	(23)	4	(20)	29	(72)	2	(15)

confined to the junior high school boys' and girls' totals.

Table 20 shows that the frequency of complete conservers (v.d.1) is consistent from question pair to question pair. Approximately 65 per cent of grade 9 boys and 25 per cent of grade 9 girls can be classed as complete conservers. It was noted above that only such (v.d.1) subjects would meet Elkind's (1961c) criterion for volume conservation. He found 68 per cent of boys and 40 per cent of girls at grade 9 level to be conservers of volume.[7]

The frequencies for the apparently anomalous cases $(v.\bar{d}.1)$, $(\bar{v}.d.1)$, and $(v.\bar{d}.\bar{1})$ shown in Table 19 are small in most cases, but together account for about 15 per cent of all subjects in junior high school. It may be concluded that both $(v.\bar{d}.\bar{1})$ and $(v.\bar{d}.1)$ for boys, and $v.\bar{d}.1$ for girls, are very close to, if not, zero. The eight per cent of girls who answer in $(v.\bar{d}.\bar{1})$ fashion may be considering factors other than weight or volume as causing displacement (e.g. diameter of immersed object relative to the container). The case $(\bar{v}.d.1)$ accounts for the response patterns of about six to eight per cent of boys and about four to five per cent of girls in junior high school. These subjects probably either misunderstand the verbal question, or find the displacement question easier to answer than the verbal question. Such subjects should be classed as conservers of volume, but would not be so classed on Elkind's criteria. In any case, the proportion of subjects in this category is low.

The case $(\bar{v}.\bar{d}.\bar{1})$ was interpreted above as conservation of neither weight nor volume. If this is a correct interpretation, then such subjects would be low scorers on the weight conservation test. Of the

TABLE 20

FREQUENCY, MEAN FREQUENCY, AND MEAN PER CENT OF RESPONSE PATTERNS ($\bar{v}$.d.1), (v.$\bar{d}$.1), AND (v.$\bar{d}$.$\bar{1}$), JUNIOR HIGH

Response Pattern	19-20	Question Pair Frequencies 21-22	23-24	25-26	27-28	29-30	Mean Frequency	Mean Per Cent
				Boys				
$\bar{v}$.d.1	19	55	20	13	17	22	24	7.3
v.$\bar{d}$.1	16	16	13	10	15	7	13	4.0
v.$\bar{d}$.$\bar{1}$	15	6	7	7	8	13	9	2.7
				Girls				
$\bar{v}$.d.1	16	25	8	8	12	13	14	4.5
v.$\bar{d}$.1	11	10	4	7	3	5	7	2.2
v.$\bar{d}$.$\bar{1}$	44	16	22	27	20	20	25	8.0

137 junior high subjects who responded in the $(\bar{v}.\bar{d}.\bar{l})$ pattern for more than one of the six question pairs, only 65 per cent responded correctly to more than half of the 18 weight conservation tasks. For the remainder of the junior high school subjects, 93 per cent responded correctly to more than half of the weight conservation tasks. The corresponding contingency table (Table 21) has a highly significant chi-square ($\chi^2 = 73.5$, $df = 1$, $p \ll 0.001$), indicating that the performance on weight conservation tasks by $(\bar{v}.\bar{d}.\bar{l})$ subjects is significantly lower than the performance by the remainder of subjects in the sample of junior high school students.

Finally, Table 19 shows that the frequency of $(\bar{v}.d.\bar{l})$ well exceeds chance level. Subjects who respond in this pattern account for about seven to eight per cent of boys, and about twenty per cent of girls. Hypothesis 3.3 is that this response pattern is the source of the difference between verbal and displacement questions. The results support this hypothesis. Figure 2 shows how the proportions of conservers for both verbal and displacement questions are made up of the different response patterns, with the predominant patterns being complete conservation, and conservation of weight in the displacement question. An explicit example of $(\bar{v}.d.\bar{l})$ reasoning is given by a grade 8 subject in explanation of an incorrect response to displacement question 26 (ball-sausage): "It doesn't make any difference what shape or size it is because it still has the same weight." A grade 9 subject wrote in explanation of an incorrect response to displacement question 22 (unfolding of rolled lead sheet): "The weight was the same so if you immerse it, it will take up more room but the water level will rise the

TABLE 21

WEIGHT CONSERVATION PERFORMANCE OF $(\bar{v}.\bar{d}.\bar{l})$ AND NON-$(\bar{v}.\bar{d}.\bar{l})$

SUBJECTS (JUNIOR HIGH)

	Weight Conservation Scores	
	0-9	10-18
$(\bar{v}.\bar{d}.\bar{l})$ Subjects	48	89
Other Subjects	37	466

Chi-square = 73.5, *df* = 1, $p \ll 0.001$

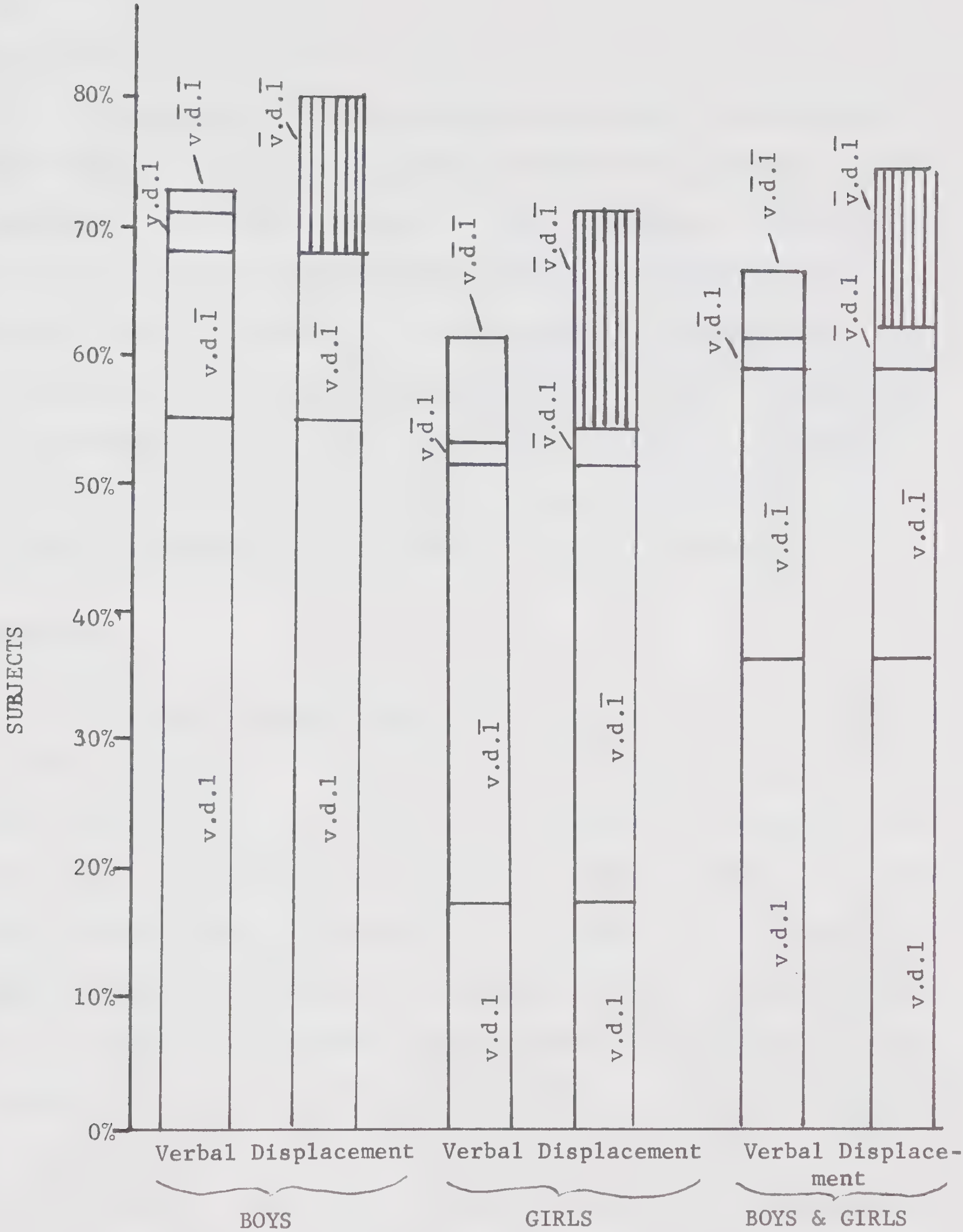

Figure 2

Response Patterns of Volume Conservers for Both Verbal and Displacement Questions 25 and 26 (Ball-Sausage Transformation)

same amount."

An additional note may be made at this point. In junior high school grades the case $(v.d.\bar{l})$ accounts for 10 to 15 per cent of boys' responses and for 30 to 40 per cent of girls' responses. The case $(\bar{v}.\bar{d}.l)$ accounts for 5 to 10 per cent of boys' responses and 30 to 40 per cent of girls' responses. It is thus possible to respond to verbal conservation of volume questions correctly without understanding the displacement law $((v.d.\bar{l}))$. The reverse is true for few boys and practically no girls. The relationship between the displacement law and volume conservation will be further discussed in Chapter V.

Conclusions

The evidence supports hypotheses 3.1 and 3.2, but not hypothesis 3.3. With respect to 3.1, from 44 per cent of students in grade 7 to 18 per cent of students in grade 12 may be classed as nonconservers of volume using a judgement-only criterion in a verbal question, e.g. ball-sausage transformation. With respect to 3.2, more boys than girls conserve volume above grade 7. With respect to 3.3, no definite result emerged. One of the rigid-body transformations was significantly more difficult than any of the other transformations, although the other two were the least difficult of all transformations. It appears however that there might be a continuum of difficulty rather than a dichotomy, and the relative magnitude of the change in surface areas which occurs in the transformation might be a major factor in determining the difficulty. With respect to 3.4, for junior high school grades combined, nearly 15 per cent of subjects answered the displacement question

correctly but not the verbal question, but did not understand the displacement law. These subjects account for most of the difference between proportions of verbal conservers and of displacement conservers.

SCHOLASTIC APTITUDE AND SCIENCE ACHIEVEMENT

Scores on a standardised science achievement test and on SCAT, both tests administered by the Alberta Department of Education, were available for 79 of the 101 boys and 93 of the 106 girls in grade 9. The hypotheses to be considered in relation to these test results are:

4.1 No sex difference in mental ability exists in the sample tested for volume conservation.

4.2 A tendency exists for subjects whose scores are below the mean in a test of weight conservation to have scores below the mean in a test of science achievement.

To test 4.1, it was assumed that grade 9 students for whom scores on the SCAT test were available are representative of the sample as a whole. SCAT scores "can confidently be interpreted as a measure of 'general intelligence.'" (Buros, 1965). Although the SCAT scores were available as percentiles, the verbal and quantitative subtotals were available as stanines. Accordingly a one-way analysis of variance was used to test for sex difference in each of the SCAT subtotals. Results are presented in Table 22, and show that no significant difference exists between boys' and girls' scores on either SCAT verbal or SCAT quantitative subtotals at the 0.05 level.

Contingency tables (2 x 2) showing the relationship between

TABLE 22

ANALYSIS OF VARIANCE FOR BOYS' AND GIRLS' SCORES ON (A) SCAT-VERBAL, AND (B) SCAT-QUANTITATIVE

Source	SS	MS	df	F	p
(A) SCAT-VERBAL					
Groups	6.8	6.83	1	2.24	0.14
Error	519.3	3.05	170		
Means: Boys' = 4.6, Girls' = 5.0					
(B) SCAT-QUANTITATIVE					
Groups	1.4	1.42	1	0.38	0.54
Error	633.4	3.73	170		
Means: Boys' = 5.1, Girls' = 5.3					

weight conservation scores and science achievement are presented in Table 23. These tables show that 19 per cent of boys and 15 per cent of girls score below the median in the weight conservation test and above the median in the science achievement test. If performance on these two tests were unrelated, then the proportion of subjects in the cell of interest (below the median in weight conservation, above the median in science achievement) would be 0.25. Taking the 95 per cent confidence interval of a proportion as $1.96\sqrt{(pq/N)}$ (Ferguson, 1966, p. 158), it may be seen that the proportion 0.25 lies within a 95 per cent confidence interval of 0.19 ($N = 79$), but not of 0.15 ($N = 93$). The confidence intervals are for boys, 0.19 ± 0.08, and for girls, 0.15 ± 0.07. Thus it appears that girls who score below the median on the weight conservation test are likely to score below the median on science achievement.

Product moment coefficients of correlation between performance on the weight conservation test and science achievement are significant: $r = 0.27$ ($t = 2.47$, $p = 0.02$) for boys, and $r = 0.36$ ($t = 3.70$, $p < 0.01$) for girls. The relationship appears to be stronger for girls, although the difference between boys' and girls' coefficients is not significant ($zr = 0.64$, $p = 0.13$) (Ferguson, 1966, pp. 187-188). It may be concluded therefore that science achievement is related to performance on the weight conservation test.

ATOMISTIC SCHEMES

The hypothesis to be considered in connection with the atomistic

TABLE 23

CONTINGENCY TABLES SHOWING RELATIONSHIP BETWEEN WEIGHT CONSERVATION SCORES AND SCIENCE ACHIEVEMENT

	Weight Conservation	
Science Achievement	Below Median	Above Median
	Boys	
Below Median	22	16
Above Median	15	26
	Girls	
Below Median	31	17
Above Median	14	31

schemes test is:

5.1 Scores on the atomistic schemes test correlate with scores on each of the three-item verbal tests of volume conservation.

Table 24 presents product-moment coefficients of correlation between scores on the atomistic schemes test and scores on the verbal volume conservation tests. Coefficients are significant in most cases, ranging from zero to 0.42 for subjects of the same sex in the same grade.

SUMMARY OF CONCLUSIONS

The results generally support the hypotheses advanced in Chapter I, except for hypotheses 3.3 (rigid-body transformations are less difficult than plastic-body transformations). The main conclusions reached in the foregoing analysis of results will be summarised below, and the results and conclusions will be discussed further in Chapter V.

1. Some junior high school students--from 10 to 20 per cent in grade 7--were found to be nonconservers of weight in simple transformations like change of shape.

2. From 20 to 80 per cent of secondary students from grade 7 through 12 were found to be nonconservers of weight in more complex transformations like change of state. More girls than boys were nonconservers of weight in complex transformations.

3. In general, proportions of nonconservers of weight

TABLE 24

PRODUCT-MOMENT COEFFICIENTS OF CORRELATION BETWEEN ATOMISTIC SCHEMES TEST AND (A) RIGID-BODY VOLUME CONSERVATION, (B) PLASTIC-BODY VOLUME CONSERVATION

Grade	A		B		N	
	M	(F)	M	(F)	M	(F)
7	.18*	(.18*)	(.11)	(.00)	107	(99)
8	.42*	(.32*)	(.30*)	(.05)	120	(108)
9	.15	(.33*)	(.12)	(.27*)	101	(106)
10-12	.25*	(.37*)	(.01)	(.21*)	141	(124)

* = $p < 0.05$

decreased from grade 7 through 12.

4. For boys from 40 per cent in grade 7 to five per cent in grade 12, and for girls from 40 per cent in grade 7 to 20 per cent in grade 12 were found to be nonconservers of volume.

5. In every grade above grade 7 significantly greater proportions of girls than boys were classed as nonconservers of volume.

6. Volume conservation questions probably lie on a continuum of difficulty according to the nature of the transformation.

7. The main contributing factor to an excess of displacement-question volume conservers over verbal-question volume conservers was a group of subjects, mostly girls, who conserve weight not volume in the displacement question because they do not understand the displacement law.

8. For boys from 40 per cent in grade 7 to three per cent in grade 12, and for girls from 73 per cent in grade 7 to 50 per cent in grade 12 do not understand the law of displacement (immersed objects displace their own volume of water).

9. Science achievement was found to correlate with performance on the weight conservation test.

10. Scores on the atomistic schemes test were found to correlate with scores on the verbal volume conservation tests.

FOOTNOTES - CHAPTER IV

1. A summary of the transformations in the weight conservation questions can be found in Chapter III, pp. 72-73.
2. The method by which trends were detected is described on p. 90.
3. Questions in the displacement law test are given in full in Appendix A.
4. Product-moment coefficients of correlation between scores on the two sets of three items range from 0.46 (grade 8 girls) to 0.68 (grade 9 boys).
5. To explain further, since

   verbal conservers = $v.d.l + v.\bar{d}.l + v.d.\bar{l} + v.\bar{d}.\bar{l}$,

   and displacement conservers = $v.d.l + \bar{v}.d.l + v.d.\bar{l} + \bar{v}.d.\bar{l}$

   = verbal conservers $- v.\bar{d}.l - v.\bar{d}.\bar{l} - \bar{v}.d.l - \bar{v}.d.\bar{l}$,

   therefore, if $v.\bar{d}.l = \bar{v}.d.l = v.\bar{d}.\bar{l} = 0$,

   displacement conservers = verbal conservers $- \bar{v}.d.\bar{l}$.
6. Question 32 compares displacement levels for equal volume spheres of different weight, question 33 compares displacement levels for heavy small sphere and light large sphere, question 36 compares displacement levels for similar jars with different weights.
7. Elkind's results appear in Table 13, p. 99.

CHAPTER V

DISCUSSION

A number of questions may be asked in relation to the results presented in Chapter IV. Why do so many subjects who conserve weight in simple transformations fail to conserve weight in more complex transformations like change of state? What relationship exists between the displacement law and volume conservation? How can the sex differences be explained? These questions will now be discussed in an attempt to characterise the development of quantity concepts beyond the age of 12 years.

NONCONSERVATION OF WEIGHT IN COMPLEX TRANSFORMATIONS

Although most subjects conserve weight in the simple transformations, many seem prepared to accept that weight might vary in the complex transformations in questions 12 through 15. In question 12, the transformation is the heating to redness of an aluminum bar, in 13, the melting of ice in a sealed plastic bag, in 14, the evaporation of a small amount of gasoline in a sealed metal can, and in 15, the partial burning of a crumpled piece of paper in a sealed glass jar.

Table 6 (Chapter IV, p. 85) shows the proportions of subjects who conserve in these transformations. For groups of subjects of the same sex in the same grade, the proportions of subjects who believe weight changes in these transformations range from 17 per cent (grade 12

boys, question 12) to 82 per cent (grade 7 boys, question 14). Table 8 (Chapter IV, p. 89) shows that generally boys give significantly more correct responses to questions 12 through 15 than do girls.

Three explanations of failure to conserve in the complex transformations could be advanced: (a) that the questions are misleading or "tricky", (b) that subjects have logically (though not necessarily physically) sound reasons for their incorrect response, or (c) subjects have not coordinated weight, volume, and density concepts, and when they do not understand the transformation, they are forced to rely on the perceptual aspects of the situation.

According to the first explanation, the questions are misleading because the subjects attention may be distracted away from the system of interest towards parts of the system, or towards irrelevant aspects of the situation. For instance in question 5 (inversion of a conical flask) subjects might be distracted by the contents of the flask (air), and indeed some subjects' written explanations refer to air or air pressure (see Appendix B). Generally however the reasons which subjects give for their responses are not of this type. Furthermore, two experimental precautions were taken against this kind of distraction occurring. First, the experimenter carefully cautioned subjects at the beginning of the test that there were "no tricks" and that many of the questions would be very easy. Second, the question was always asked in terms of what weight the balance would show. The system of interest was always returned to the balance platform as the final step in the demonstration, thus focusing attention on the system as a whole.

Even if this first explanation were to be accepted, the matter of why the questions are misleading would not be resolved. According to the second explanation (that subjects have logically sound reasons for not conserving) failure in the complex transformations could be explained in terms of elementary physical misconceptions. For example, in question 12 (heating of a metal bar) subjects might ascribe the property of weight to heat. In 13 also (melting of ice) heat gain is involved. In 14 (evaporation of gasoline) subjects might respond incorrectly if they do not ascribe the property of weight to gases. In 15 (burning of paper) all of the aspects of the previous transformations just mentioned are involved, complicated by the aspect of chemical change, a process which subjects may understand dimly, if at all.

If heat gain is thought to be accompanied by weight gain, then subjects' reasons for incorrect response to question 12 (heating of metal bar) and 13 (melting of ice) might be expected to reflect this notion. In fact this is not the case. Of 18 reasons given by subjects for incorrect response to question 12, only four refer to heat changing the weight of the bar. No reasons given for incorrect response to 13 refer to heat. In itself, heat is apparently not considered to be a factor by subjects.

If an underlying factor in failure to conserve in question 14 (evaporation of gasoline) is absence of the notion that gases have weight, then performance on question 14 might be expected to correlate with performance on question 16 (oxygen released from cylinder) or question 17 (football pumped up). Table 25 presents phi-coefficients of correlation of performance on question 14 with performance on

TABLE 25

PHI-COEFFICIENTS OF CORRELATION BETWEEN PERFORMANCE ON QUESTION 14 WITH PERFORMANCE ON QUESTIONS 16 AND 17

Grade	Question 16 M	Question 16 (F)	Question 17 M	Question 17 (F)	N M	N (F)
7	.02	(-.07)	.08	(-.05)	107	99
8	-.05	(.13)	.02	(.22*)	120	(108)
9	.06	(.14)	.19	(.11)	101	(106)
10-12	.26*	(.24*)	.18*	(.17)	141	(124)

* $p < 0.05$

questions 16 and 17. Only in senior high school are these coefficients significant. Moreover, for junior high school students who answer both 16 and 17 correctly, question 14 is found to be significantly more difficult than question 13 (melting of ice) (z = 2.7, $p < 0.01$) when a z-test of significance of difference between correlated proportions is applied. Thus there is more involved in question 14 than the notion that gases have weight. Apparently explanations of nonconservation in terms of physical misconceptions are not satisfactory.

One physical aspect of question 13 (melting of ice) is represented in question 6 (setting of jelly)--that is change from solid to liquid or vice versa, but even if the difficulty of question 13 can be explained in terms of question 6, what makes question 6 difficult? In question 6 the change occurs inside a sealed container--"nothing gets in, nothing gets out." No transfer of heat is involved, no change of volume, and no change of shape. Subjects are asked to visualise the orange liquid in the sealed jar turn to a solid jelly. From 11 per cent (senior high boys) to 62 per cent (grade 7 girls) of subjects thought the weight would change.

The reason may be that subjects do not understand the transformation, or in other words, they cannot construct a grouping of operations to represent the transformation. As a result, such subjects are forced to consider in isolation of the transformation the successive configurations--orange liquid and orange solid. As a class, solids are "heavier" than liquids, or press down harder on the hand. In an egocentric weight concept the balance platform is conceived of as an extension of the hand (Piaget & Inhelder, 1968, pp. 34-40). Thus

as long as the notion of weight depends upon concrete operational thinking, failure to understand (i.e. construct a grouping of operations for) a given transformation may result in regression to egocentric or perception-bound notions of weight.

Question 7 affords another illustration of this kind of regression to perception-bound notions. In question 7 a wooden block is moved from the centre of the balance platform to overhang the edge. Again, from 16 per cent (senior high boys) to 62 per cent (grade 7 girls) of subjects think the weight will change. In this case, it is unlikely that the actual weight of the block is thought to change. The transformation which subjects do not understand is a transformation of the balance-block system, not just a transformation of the block. Since students do not understand the mechanism of the balance, they may be forced to rely on intuitive representations of the successive configurations. These can be seen to be egocentric in nature. Subjects "feel" that the balance gives a "truer" weight if the object is placed in the centre of the platform. When hefting, the object is always placed firmly in the centre of the palm. Subjects "feel" that full contact of the lower surface of the block with the platform is necessary for the full weight to be registered. Only where surfaces touch is the weight "felt" to act. These types of reasoning can be found in subjects' written reasons for incorrect response to question 7 (Appendix B, pp. 172-174). Of 18 reasons for incorrect response, only two refer to ideas of the balance as a level arm.

It is proposed then, as the third explanation for nonconservation of weight in complex transformations, that when some subjects do not

understand the transformation they are forced to rely on intuitive notions which are usually perception-bound or egocentric. It is further proposed that the problem is endemic to Stage III or Substage IVA subjects (i.e. nonconservers or transitional conservers of volume), because a stage IVB subject (i.e. a necessary conserver of volume) has succeeded in correctly relating weight, volume, and density. For instance, in question 14 (evaporation of gasoline) perceptual factors are irrelevant for the subject who reasons that although the gasoline occupies a far greater volume, its density has decreased in inverse proportion to the volume, and thus the weight remains unchanged.

If this proposition is sound--that weight conservation in the complex transformations is a less difficult problem for necessary conservers of volume than for other subjects--then it would be expected that performance on questions 12 through 15 would correlate with performance on volume conservation tasks. Table 26 presents point-biserial coefficients of correlation between (a) performance on question 12 through 15, and (b) scores on the two three-item verbal tests of volume conservation (for rigid-body and plastic-body transformations). Most of these coefficients are significant, indicating that volume conservers are more likely than nonconservers to conserve weight in the complex transformations.

As further evidence of a connection between (a) weight conservation in complex transformations and (b) volume conservation, a

TABLE 26

PHI-COEFFICIENTS OF CORRELATION BETWEEN VOLUME CONSERVATION PERFORMANCE AND COMPLEX TRANSFORMATION WEIGHT CONSERVATION PERFORMANCE

Grade	N M	N (F)	12 M	12 (F)	13 M	13 (F)	14 M	14 (F)	15 M	15 (F)
RIGID-BODY TRANSFORMATIONS										
7	107	(99)	.15	(.32*)	.25*	(.26*)	.17	(-.04)	.13	(.14)
8	120	(108)	.23*	(.21*)	.33*	(.12)	.20*	(-.06)	.14	(.01)
9	101	(106)	.26*	(.12)	.33*	(.14)	.17	(.15)	.10	(-.04)
10-12	141	(124)	.43*	(.24*)	.45*	(.29*)	.40*	(.30*)	.26*	(.16)
PLASTIC-BODY TRANSFORMATIONS										
7	107	(99)	.20*	(.39*)	.24*	(.37*)	.14	(-.09)	.08	(.19)
8	120	(108)	.29*	(.34*)	.30*	(.22*)	.22*	(-.05)	.18*	(.16)
9	101	(106)	.24*	(.14)	.40*	(.14)	.19	(.16)	.25*	(-.07)
10-12	141	(124)	.31*	(.19*)	.45*	(.31*)	.26*	(.16)	.24*	(.18*)

* $\underline{p} < 0.05$ ($\underline{z} = \phi\sqrt{\underline{N}}$)

sex difference is found for both, whereas no sex difference is found for weight conservation in simple transformations.

Of the three explanations advanced for nonconservation of weight in the complex transformations, the third seems to be most consistent with the evidence presented. To summarise the third explanation, subjects who have attained volume conservation and have established correct relationships among weight, volume, and density may have no difficulty conserving weight in the complex transformations. For such subjects, volume changes may be coordinated with density changes. Subjects who have not attained volume conservation may have to rely on the construction of a grouping of concrete operations for a given transformation. If such a grouping cannot readily be constructed (i.e. if the transformation is difficult to understand), these subjects may be consequently forced to rely on the perceptual aspects of the successive configurations, and thus may fail to conserve weight.

VOLUME CONSERVATION AND THE DISPLACEMENT LAW

Sex differences were found in both attainment of volume conservation and understanding of the displacement law. An immediate question is how are these two sex differences related, or more fundamentally, how are volume conservation and the displacement law related? Since the sex difference in the displacement law appears to be greater than in volume conservation, the displacement law may be the more basic concept. On the other hand, Table 27 indicates that

TABLE 27

CONTINGENCY TABLES OF DISPLACEMENT LAW UNDERSTANDING AGAINST VOLUME CONSERVATION, JUNIOR HIGH

	Displacement Law	
	0-4	5-8
Boys		
Nonconservers	50	46*
Conservers	47*	185
Girls		
Nonconservers	108	37*
Conservers	103*	65
F Total		
Nonconservers	158	83*
Conservers	150*	250

* cells of interest

more subjects conserve volume without understanding the displacement law than vice versa. Table 27 is a 2 x 2 contingency table for junior high school students with understanding of the displacement law as one variable, volume conservation attainment as the other. The cells of interest are marked with asterisks. About twice as many subjects conserve volume without understanding the displacement law as understand the law without conserving volume. For boys separately, there are nearly equal numbers of subjects (about 15 per cent) in each category, but for girls separately, there are 33 per cent of subjects who conserve volume without the displacement law compared with 12 per cent of nonconservers with the law.

Hence the following propositions are advanced:

(a) For secondary school students, discovery of the displacement law leads almost automatically to volume conservation.

(b) The sex difference in volume conservation can be related to the sex difference in the displacement law.

According to Piaget (Piaget & Inhelder, 1968, Ch. VIII), the first step in discovery of the displacement law is dissociation of volume from the other properties of the body. Consider a subject who has acquired the prerequisite factors for volume conservation--weight conservation, notions of continuity, and the proportionality scheme. For such a subject, volume conservation may follow quickly upon dissociation of the volume property from weight and from the other properties of a body. Thus discovery or learning of the displacement law might precipitate for this subject the acquisition of volume conservation. Evidence that this precipitation may occur is provided by

the Vinh-Bang-Inhelder experiment (Inhelder, 1968, p. 318; Piaget & Inhelder, 1968, p. xviii) referred to above (p. 39), in which 12-year-old subjects rapidly acquired volume conservation in successive trials of prediction, demonstration, and explanation of displacement levels. If it is assumed that the prerequisite notions to volume conservation are attained by the age of 13, then for secondary school students, discovery of the displacement law may be a precipitating factor in the acquisition of conservation of volume. Many of the girls who do establish volume conservation do so, as Table 27 indicates, without first establishing the displacement law. To establish volume conservation in this way might be less likely or possibly more intellectually demanding than to establish volume conservation with the facilitation provided by discovery of the displacement law. Thus the sex difference in volume conservation attainment may be traced to the sex difference in the displacement law, and this in turn may be simply explained in terms of differences between boys' and girls' day-to-day experiences.

SUMMARY

The conclusions reached in the preceding discussions will now be summarised. The summary may be taken to represent a list of the characteristics of the various states of development of physical quantity displayed by secondary school students.

1. The period from grades 7 through 12 seems to be the time when for most students a quantified concept of volume is acquired. Though

some students have already acquired the volume concept by the end of grade 7, some have not acquired it by the end of grade 12.

2. Acquisition of a quantified concept of volume appears to be accompanied by (a) achievement of notions that matter consists of particles of invariant weight and volume, and (b) establishment of correct relationships between weight, volume, and density.

3. Discovery of the law of displacement of liquids may facilitate the acquisition of volume conservation without constituting a necessary prerequisite.

4. Subjects who may normally be classed as conservers of weight but nonconservers of volume may fail to conserve weight in a complex transformation like change of state, through being unable to construct a grouping of operations. Subjects who conserve volume may, through coordinating changes in volume and density, be able to conserve weight more readily in the complex transformation. That is to say, for these subjects, the perceptually misleading aspects of the situation may be irrelevant.

5. Possibly because of differences in experience, far fewer girls than boys have established the law of displacement at any stage in secondary school. A lesser sex difference in volume conservation may thus be a reflection of the sex difference in acquisition of the displacement law. This sex difference in volume conservation may in turn explain a sex difference in conservation of weight in complex transformations.

The results of the present experiment indicate that if the existence of a system of correctly related concepts of weight, volume,

and density can be inferred from the presence of volume conservation, then the proportions of students at grade 9 level who have established such a system probably lies between 20 and 70 per cent of girls, and between 70 and 80 per cent of boys (depending on the criteria of conservation employed).[1]

FOOTNOTES - CHAPTER V

1. The lower percentage is based on the criterion of "complete conservation" described in Chapter IV (p. 109). It applies to subjects who understand the displacement law and conserve volume. The higher percentage is based on the criterion of correct response to at least two of the three plastic-body transformation verbal tests of volume conservation.

CHAPTER VI

SUMMARY AND IMPLICATIONS

In this final chapter, a summary of the study is presented, followed by a discussion of the implications of the study for (a) science curriculum in secondary schools, (b) methodology of volume conservation testing, and (c) further research.

SUMMARY

The study sought to determine levels of acquisition of concepts of weight and volume in secondary school students, and to relate these levels to grade, sex, science achievement, and methodology of testing. A total of 906 students in grades 7 through 12 were tested in a normal classroom setting.

The test consisted of four parts--(a) a set of 18 weight-conservation questions involving simple transformations like change of shape, and complex transformations like change of state, (b) a set of 12 volume-conservation questions involving two kinds of transformation and two kinds of question, (c) a set of eight displacement-law questions to test subjects' understanding of the phenomenon of displacement of fluids, and (d) a set of eight atomistic-schemes questions, to test aspects of subjects' particulate representations of volume changes. Except for the atomistic schemes questions which formed a written test, the questions were administered orally with demonstrations.

The findings of the experiment may be summarised as follows:

1. For about ten to twenty per cent of students, the concept of weight develops during the junior high school grades.

2. Many students who conserve weight in simple transformations like change of shape do not conserve in complex transformations like change of state.

3. For about 40 to 50 per cent of boys and about 20 to 30 per cent of girls, the concept of volume develops during secondary school grades, while for about 20 to 30 per cent of girls, the concept of volume has not developed by grade 12.

4. In grade 7, about 30 per cent of girls and about 60 per cent of boys respond correctly to more than half of the items on the displacement law test. By grade 12 virtually all boys but only about 50 per cent of girls attain this level of understanding of the displacement law (more than half of the items correct).

5. The proportion of volume conservers found in a given test depends on the transformation used in the test, and on whether the question is asked verbally or in terms of displaced levels of water.

6. Performance on the 18-item weight-conservation test correlates significantly with science achievement. Girls who score below the median on the weight-conservation test are more likely to score below the median on science achievement than above.

7. Significant positive correlations exist between acquisition of volume conservation and performance on the atomistic schemes test.

IMPLICATIONS FOR SCIENCE CURRICULUM

Quantification is a major aspect of science. The logical necessity which accompanies conservation seems to obliterate all recollection of the crude notions which precede its acquisition. Thus for the scientist or teacher, difficulties which might accompany notions of physical quantity in secondary school students may be hard to understand. These difficulties may be better understood if a sequence of development of physical quantity concepts can be described.

Moreover, if learning is more than the registration of successive empirical events experienced first-hand or vicariously; if learning involves interaction between experience and developing thought structures, then the restrictions placed by each of these two upon the other have to be taken into account in the development of science curricula. The experiences which the science teacher may arrange for his students may not necessarily induce the conceptual learning which he anticipates. To illustrate, explicit teaching about the particulate nature of matter may be less effective in achieving its purpose than experience in measuring quantity, since the concept of particulate matter may develop spontaneously as the invariance of physical quantity in transformations becomes established.

In more specific terms, implications of the findings of this study for science teaching and curriculum include the following:

1. Quantity concepts appear to be appropriate items of curriculum content in junior high school.

2. It may not be assumed that terms like "mass", "weight",

"volume", "density", etc. have clear or distinct meaning for students in secondary school. Careful, precise, and frequent use of such terms in science teaching may assist the student to differentiate the associated concepts one from another.

3. Practice in weighing and measuring volume by displacement may assist some students to acquire a quantified volume concept and hence weight-volume- density relationships.

4. Evidence that subjects can spontaneously acquire atomistic schemes in acquiring quantified volume indicates that kinetic-molecular concepts might be established in conjunction with necessary conservation of weight in change-of-state or chemical-change transformations.

5. Since conservation necessarily accompanies acquisition of quantification of weight or volume, concepts of conservation of other physical quantities like velocity, momentum, or energy might necessarily accompany their quantification. Such conservation laws are not and cannot be empirical laws, but follow as logical necessity upon the understanding of fundamental changes or interactions of matter. For instance, an appropriate approach to the concepts of energy and its conservation might be for students to quantify or measure energy in various forms.

6. If the sex differences found in the present experiment have been correctly related to differences in boys' and girls' experiences, girls' science achievement may be improved by means of confrontation with appropriate experience. Of course the problem is probably not so simple, and may involve interest, attitude, motivation,

etc.

IMPLICATIONS FOR METHODOLOGY OF VOLUME CONSERVATION TESTING

In the review of the literature in Chapter II, a number of different approaches to volume conservation testing were discussed, and it has been demonstrated in the present experiment that the type of transformation used, the type of question asked, and the criteria of conservation adopted, all affect the level of conservation found in a given experiment. Evidence has also been reported (p. 39) (Inhelder, 1968; Piaget & Inhelder, 1968) that 12-year-old subjects can quickly acquire volume conservation when given appropriate experience. Thus volume conservation testing is a difficult process, reflecting the difficulty and abstract nature of the volume concept itself. Specific implications for volume conservation testing, and also for interpretation of volume conservation experiments, may be summarised as follows:

1. Since transitional conservers find some transformations more difficult than others, volume conservation testing should involve a number of transformations.

2. Since terms like "volume" may have no definite meaning for subjects, and since many subjects do not understand the phenomenon of displacement of fluids, volume conservation testing should include specific questions about amount of space or room occupied.

3. An objective operational measure (displacement of water levels) should be used in addition to references to space or room

occupied, in case subjects are led to answer only in terms of perceptual notions of volume.

4. Subjects need not be required to give correct verbal explanations of conservation responses in order to be classified as conservers, because explanations may represent overly restrictive criteria.

5. If actual demonstration of displacement levels is not performed before or during the experiment, the test may detect all subjects who do not conserve instead of just those who cannot conserve. The latter category includes only those subjects who lack the prerequisite factors to volume conservation. For some subjects who do not conserve, recognition that volume is the causative factor in displacement of water levels may precipitate acquisition of volume conservation.

IMPLICATIONS FOR FURTHER RESEARCH

The present findings in relation to volume conservation testing indicate that many of the studies reviewed in Chapter II might well be repeated with changes in methodology. Unanswered questions relate to (a) the mode of acquisition of volume conservation, (b) levels of acquisition of other physical quantity concepts (momentum, energy, etc.) and (c) relationships between physical quantity and atomistic schemes.

More specifically, possible research activities include the following:

1. normative studies of volume conservation using carefully

devised testing procedures;

2. further studies of relationships among volume, other physical quantities, and nature of curriculum experience, etc.;

3. determination of levels of acquisition of physical quantities like velocity, energy, etc.;

4. determination of sex differences in formal operational concepts other than volume;

5. investigation of the possibility that extent of increase of surface area may be an important factor in determining the difficulty of volume conservation transformations;

6. examination of the roles in acquisition of volume conservation of concepts of continuity, relations between volume and boundary surfaces, atomistic schemes, and the proportionality scheme; and

7. construction and testing of learning hierarchies for acquisition of volume conservation.

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APPENDICES

APPENDIX A

APPENDIX A

TEST ITEMS

The 46 test items are described below. For the conservation items, initial and final configurations are specified, and the transformation described. For the displacement law test, the configurations of which displacement levels were compared are specified. For the atomistic schemes test, actual questions are reproduced.

Weight Conservation

1. A cylinder of clay approximately 12 cm. long, 2 cm. diameter (initial configuration) was broken into five or six pieces (final configuration).

2. A prism of clay, 17 cm. long, 1 cm. square cross section (initial configuration) was formed into a ring by joining its ends (final configuration).

3. A metal stand, 25 cm. in height, with a circular base, diameter 11.5 cm., had a right-angle clamp holder resting at the bottom (initial configuration). The clamp holder was raised to the top of the stand and clamped (final configuration).

4. A 400 ml. flask contained about 50 ml. of syrup and a glass stirring rod (initial configuration). About 50 ml. of water was added, and the mixture stirred. The flask plus mixture plus stirring rod formed the final configuration.

5. A 300 ml. conical pyrex flask was placed on the balance platform (initial configuration). It was turned upside down (final configuration).

6. An 8 oz. glass jar almost full of orange fluid and fitted with a metal screw cap formed the initial configuration. Ss were told that the liquid was a solution of orange jelly crystals, and were asked to imagine that it was allowed to set until "hard," nothing getting into or out of the jar. The jar containing orange jelly formed the final configuration.

7. A wooden cylinder, length 3.9 cm., diameter 5.0 cm. was placed base down on the centre of the balance platform. (initial configuration). It was moved away from, and in a perpendicular direction to, the central knife edge, to overhang the balance platform by almost half its own diameter (final configuration).

8. Two cotton wool balls were placed on the balance platform (initial configuration). One was removed, and the other increased in

volume by a factor of about two (final configuration).

9. An 8 oz. glass jar, fitted with a metal screw cap, was full of cotton wool (initial configuration). The cap was removed, the cotton wool packed down to about half its original size, and the cap replaced (final configuration).

10. A styrofoam sphere, diameter 4 cm. (initial configuration) was squeezed to a disk about 4 cm. diameter, 1 cm. thick (final configuration).

11. An 8 oz. glass jar, fitted with a metal screw cap, was about one-quarter full of sand (initial configuration). The lid was removed, a small amount (about 20 ml.) of sand was added, and the cap replaced (final configuration).

12. A bar of aluminum, 40 cm. long, diameter 1.5 cm., was placed on the balance platform (initial configuration). Ss were asked to imagine that it was heated to redness (transformation simulated) and returned to the balance platform while red hot (final configuration).

13. A plastic bag containing about 400 g. of ice cubes was placed on the balance platform. Ss were told that the bag was sealed so that nothing could get in, nothing could get out, and were asked to imagine that the ice was allowed to melt, and the bag of water placed back on the balance platform (final configuration).

14. Ss were shown a flat-sided metal can 9 cm. x 13 cm. x 19 cm. containing a small amount of liquid ostensibly gasoline (initial configuration). Ss were asked to imagine that the can was left "in the sun" until the gasoline had evaporated, but that nothing could get in or out of the can. In the final configuration, no liquid could be heard to rattle in the can.

15. Ss were shown a 32 oz. glass jar fitted with a metal screw cap, and containing a crumpled piece of charred paper (initial configuration). Ss were asked to imagine that the paper was ignited by means of focusing the sun's radiation with a hand lens, so that the paper would burn for a short while although nothing could get in or out of the jar. The sealed jar containing partially burned paper formed the final configuration.

16. A steel lecture bottle of oxygen was placed on the balance platform (initial configuration). The cock was opened so Ss could hear the release of oxygen. Ss were asked to imagine that the cock was left open until "no more oxygen came out," and the empty cylinder returned to the balance platform (final configuration).

17. Subjects were shown a football partly inflated (initial configuration) and asked to compare its weight in this form with its weight when "pumped up hard" without its shape or size being altered

(final configuration).

18. Ss were shown an alcohol burner visibly near full of fuel (initial configuration). Ss were asked what would happen to the level of fuel if the burner were lit. Their reply that the fuel level would go down was confirmed. Ss were asked to imagine that the burner was lit, allowed to burn for half an hour, extinguished, and returned to the balance platform (final configuration).

Volume Conservation

The standard form of the volume conservation questions will now be described. The configuration and transformations in each question were specified in Table 28, p. 161.

In each odd-numbered question, subjects were shown a body in the initial configuration (e.g. ball of clay) and an identical comparison body. E said "This (ball) has a certain volume--it takes up a certain amount of room. If I do this (roll the ball out into a sausage) Does it now have a bigger volume, a smaller volume, or the same? Does it now take up more room, less room, or the same?"

In each even-numbered question, subjects were shown the initial and final configurations from the previous even-numbered question. E said "When it was like this (initial configuration) if I place it in the water the level will rise. Now that it's like this (final configuration) will the level rise more, will it rise less, or will it rise the same?"

Displacement Law

An object was immersed in a container of water in each of the displacement law questions. The level of water was noted, and a second object shown to Ss. The question asked was "If I put this (the second object) in the water, will the level rise more, will it rise less, or will it rise the same?" The first and second objects were specified in Chapter III (p. 76).

Atomistic Schemes

The written test was as follows:

This test starts at #39

PLACE A MARK ON THE ANSWER SHEET FOR WHAT YOU THINK IS THE BEST ALTERNATIVE

39. When a metal bar is heated, it expands. An explanation is

A. The metal stretches because it gets soft
B. Particles of metal increase in size

TABLE 28

VOLUME CONSERVATION QUESTIONS

Question Pair	Initial Configuration	Transformation	Final Configuration
19-20	Hinged pair of wooden blocks, each 15 cm. x 2 cm. x 2 cm., folded to form a shape 15 cm. x 4 cm. x 2 cm.	Unfolding.	Shape 15 cm. x 2 cm. x 2 cm. (See Figure 3)
21-22	Lead foil strip folded to form rectangular shape 3 cm. x 7.5 cm., 12 folds.	Unfolding.	Lead foil strip 7.5 cm. x 40 cm. (See Figure 4)
23-24	Clay ball diameter 4.5 cm.	Splitting along precut plane.	Two clay hemispheres.
25-26	Clay ball, about 3 cm. diameter.	Rolling.	"Sausage", about 10 cm. long, 1.5 cm. diameter.
27-28	Clay ball, about 3 cm. diameter.	Squashing flat.	"Pancake", about 5 cm. diameter, 1 cm. thick.
29-30	Metal ingot in shape of crucible (COORS Size 0)	Melting, and pouring onto asbestos sheet.	Irregular lamina 2 to 3 mms. thick.

Figure 3

Hinged blocks used in question pair 19-20.

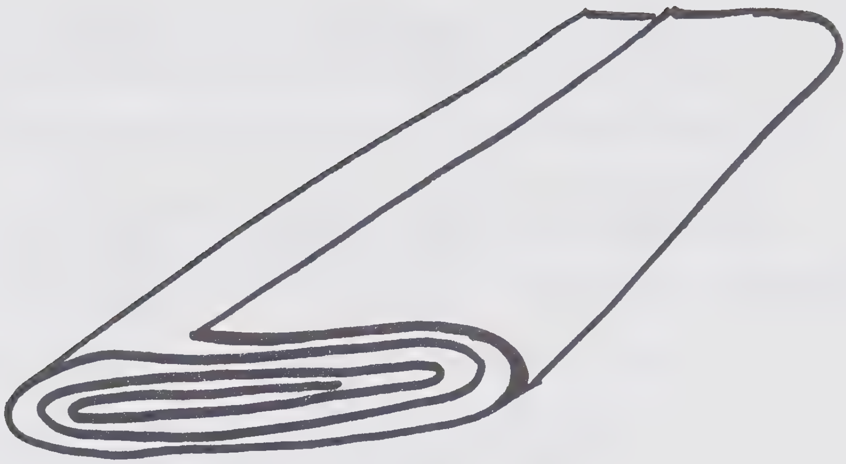

Figure 4

Lead foil roll used in question pair 21-22.

C. Particles of metal move apart
D. Air spaces in the metal expand with the heat.

40. When a thermometer is warmed, the liquid inside goes up

A. The heat gets into the liquid and makes it rise
B. The liquid is formed of small drops which expand
C. The liquid molecules soften
D. The molecules of liquid move apart from one another.

41. A grain of corn is "popped," increasing the size.

A. Small particles of corn inside blow up
B. Molecules of corn get further apart
C. Molecules of corn expand
D. The grain fills with heat.

42. A ball of modelling clay is flattened into a pancake.

A. Molecules of clay are flattened out
B. The particles of clay change their positions
C. Clay molecules decrease in size
D. Clay particles form discs.

43. A solid rubber ball is squeezed flat under a heavy weight.

A. The rubber molecules move into different positions
B. All air is squeezed out of the rubber
C. Particles of rubber become smaller
D. Rubber molecules flatten out.

44. When sugar forms a solution with water

A. The sugar forms a layer at the bottom
B. Sugar molecules break up into smaller particles
C. The sugar melts
D. Sugar molecules mix in with the water.

45. Liquids expand when heated because:

A. The distance between molecules increases
B. The heat causes some of the liquid to evaporate
C. Heat makes molecules rise
D. The molecules increase in size.

46. When the liquid in a thermometer goes down on a cold day

A. Small droplets in the liquid become harder and smaller
B. Liquid molecules contract in size
C. The liquid molecules move closer together
D. The liquid shrinks to retain its warmth.

APPENDIX B

APPENDIX B

SUBJECTS' WRITTEN EXPLANATIONS

A selection follows of subjects' written explanations of responses to conservation and displacement law questions. All explanations are given for incorrect response. Explanations for correct response are usually nearly identical, and are given in full only for questions 3 through 7, and 20. A letter code is given representing subjects' responses to the item (A = more, B = less, C = the same).

Question 3: Weight conservation--clamp raised on metal stand. Correct response = C

Grade 7.

1. (C) No mass is lost.
2. (C) From watching the scale I could see that it didn't move when the handle was touched.
3. (C) It weighs more because the clamp is sort of push more weight down.
4. (B) I think it will weight less when the thing is at the top because there will be less weight on the scale.
5. (B) It might of had air trapped in it when it was down.
6. (C) It weighs more because it has air pushing on it.
7. (A) I think it weighs more because when the man put up the clamp it goes higher and pushes down on the scale.
8. (C) I think it weighs the same because all you did was move the clamp. You did not add anything or take away anything.
9. (C) It weighs the same because nothing is given or taken away.
10. (C) I think it weighs the same because you are not taking anything off the scale or putting anything more on the scale.
11. (C) It weighs the same because no weight is lost or gained.
12. (C) Because nothing is gained or lost.
13. (C) I think it weighs the same because nothing is added and nothing is taken away.
14. (C) I don't think that a thing (objects) change weight because of you moving it up or down.
15. (C) It weighs the same because nothing was removed from the stand and nothing was added and it doesn't matter what position the clamp is in.

16. (C) I think that it weighs the same because in the first step every thing was on the stand and in the second step it was just moved higher.
17. (C) It has not changed in form. e.g. (fire to ashes).

Grades 7-8.

1. (C) Only if you take the clamp off with it way different.
2. (B) It weighed less when it was at the top because it's weight grew lighter as it lifted.
3. (A) It was more because it was farther back than it was at first.
4. (A) The clamp is tightened on the top of the bar, therefore at its highest weight possible. At the bottom it was just lying loosely, at the top pressure was applied.
5. (C) Because the clamp weighs the same but you are just moving its position.
6. (C) It was the same because there was no more or less weight added or taken.
7. (C) Because no matter what shape it is if you don't take anything off or put anything on it should be the same.
8. (C) It was the same because it wouldn't change because you moved the clamp up.
9. (C) I think it was the same because nothing was taken out of it or more put into it it was just changed in looks.
10. (C) I think it would be the same because its still is in one piece, and wherever you moved the clamp it would be the same.
11. (C) It was the same weight because all you did was moved it around and you never removed anything.
12. (C) It was the same because there was still the same amount on the scale.
13. (C) It would be the same because you still have the clamp on the stand.
14. (C) I thought it was the same because you didn't take anything off.
15. (C) It would remain the same because it won't weight any more whether it is at the top or bottom. It still has the same weight.
16. (C) I think it weighs the same because you are using the same thing. The only thing different is the thing moved to the top.
17. (C) The same thing was put on. But it was made round.
18. (C) I think it would be the same because you had the same amount of clay.
19. (A) I think it would be more because when the clay curls.
20. (B) When you join the ends the molecule in the plasticene join together.

Question 4: Weight conservation--water added to syrup in beaker.
Correct response = A.

Grade 9.

1. (B) The syrup was stirred around, and the sugar dissolved and sugar weighs more than water.

2. (C) It would weigh the same because you had mixed the water and sytes it think it will the same.
3. (C) It weighs the same because all the change is that the syrup was loosened instead of staying in one blob. It is the same.
4. (C) I think it weighs the same because when the water was added to the syrup it weighed the same as when you stirred it it also weighed the same.
5. (A) It is because when they were alone they lost a little from the temperature of the classroom.
6. (B) The syrup was heavy - it came out slow, and the water diluted it, making it lighter - and water weighs hardly anything the amount that was poured in.
7. (C) I think it will weigh the same because the water and syrup are still weighed sometime together so if you weigh them both together after it will be the same.
8. (A) I think it weighs same because of the water added syrup becomes watery.
9. (B) I think it weighs less because syrup is very heavy by itself, or with water on top. But mixed together evenly it is enlightened-somehow.
10. (C) I think C because it all weighs the same so the weight will stay the same. When you stirred it up it will still be the same weight.
11. (A) Because there is acually no change in the syrup and the water doesn't weigh hardly any.
12. (C) The beaker weighed the same when you mixed the water and syrup together because the syrup was thick and weighed a little bit. When you mixed the two together the syrup became runnier and weighed less, but with the water in it it weighed about the same.
13. (C) I think it weighs the same because it had the same amount of solution in it.
14. (B) The syrup weighed less because it was diluted in the water and most of the sugar desolved.
15. (A) When you mix things up you are breaking the chemicals in it down so it will have more chemicals in it.
16. (A) The syrup, as you stir it got heavier because with the water in there it softened up.
17. (B) It weighs less because the product is thinner. When it is thicker it is heavier.
18. (A) I say it weighs less because you've broken down the syrup with water and its thinner.
19. (B) I think it weighs less because when you mix the water it gets runnier and so it gets lighter.
20. (C) It is the same because it is the same amount by itself or together.
21. (A) Water has weight to it and when you add the water it makes the beaker heavier.
22. (C) The syrup and water that was mixed in the beaker made the molecules of water expand into the air.
23. (A) I think it will weigh more because after you stirred it, it got all mixed together so it would be heavier.

24. (A) It weighs more because you added a little water and the water had to have some weight.
25. (A) I think it ways more because you added the water to it.
26. (A) I think it weighs more because you have added water to the syrup and water weighs something.
27. (A) It would weigh more because when you add something to something else its going to get heavy.
28. (A) I think it weighs more because you added some water to the syrup. The water has weight so it must be heavier.
29. (A) You added water to the syrup.
30. (A) Because water was added to the syrup and caused it to weigh more.
31. (A) It will weigh more because you added the syrup and water.
32. (A) It weighs more because you added water and water weighs something.
33. (A) I think it weighs more because when you added the water it weighed more than just the syrup in the jar.
34. (A) It weighs more because water is a heavy liquid.
35. (A) It weighs more because you added water and water has weight.
36. (A) I think it weighs more because of the added water. The water weighs something and is added to the mixture already in the beaker.
37. (A) The water makes the syrup heavier and just adds weight.
38. (A) Before it had no liquid in it and the syrup is heavy then you added some water which would make it heavy.
39. (A) First you added syrup then water so it should weigh more.
40. (A) It weighs more because the syrup and water will add some weight to the jar.
41. (A) I think it weighs more because when you add water you put more weight in the jar.
42. (A) It weighs more because you added water and water weighs a few ounces and sometimes even more.
43. (A) It weighs more because you have added something to the container so there is more there to weigh.
44. (A) It weighs more because water is quite heavy and so is syrup. So when mixed you have more substance in the beaker and it will also weigh more.
45. (A) I think the mixture weighs more because water has some weight to it and when you mix it with the syrup that water makes the mixture heavier.
46. (A) It weighs more because you added water to the syrup.

Question 5: Weight conservation--conical flask inverted. Correct response = C.

Grade 7.

1. (C) It would weigh the same because there is no change in the glass.
2. (C) Because it is no different which way it is put on the scale.
3. (C) Because it is no different project.
4. (C) It weighs the same because there is the object.

5. (C) I think its the same because no matter how you put it it should have the same weight.
6. (C) Because the force of gravity is the same if it's upside down or if its right side up.
7. (C) I think its the same because an object is the same weight standing up or upside down.
8. (C) It is the same because nothing has been added or taken away. It has just been turned around.
9. (C) It would not make no different.
10. (C) I think it was the same because it still was the same shape.
11. (C) I think it weighed the same because it has no more weight in it and the volume is the same.
12. (C) It just weighs the same because it makes no difference which way it is.
13. (C) The weight will not change, just because the flask is turned upside down.
14. (C) It should be the same because there was nothing added and it shouldn't make any difference in what way its standing.
15. (C) It shouldn't make any difference how it's set on the scale - it still should weigh the same.
16. (C) It's the same weight because there is nothing added or subtracted.
17. (C) It will be same as if the bottom on the sample, the top on the sample will be the same.
18. (C) It wouldn't change because it didn't change in width or length.
19. (C) If you turned it over it would weight the same because its the same weight.
20. (C) Its the same thing because its all there nothing was taken or added.
21. (C) It the same because it does change it water size or volume it the same.
22. (B) It weighs less because when the jar was right side up the weight was at the bottom. When the jar was upside down the weight at the top.
23. (C) When you put more water in it it gets heavier.
24. (A) I think it will weigh more because when it is sitting fat it weighs a little. When you sat it upside down graphity pulls the weight down.
25. (A) There is more air pressure on it so it would matter which way its weighed.
26. (A) I think it would weigh a little more because of the air caught in the flask.

Question 6: Weight conservation--orange liquid turns to jelly. Correct response = C.

Grade 8.

1. (C) I think it would weigh the same because it would first get hard and the weight wouldn't change.
2. (B) When it was just sitting there was still water in it so it was heavier but when it all sets it forms sort of a jelly and the

jelly is lighter than the water.

3. (B) Less because when the jello hardens water with the chry stays in it are heavier.
4. (C) When the jello set it should way the same because nothing was added and nothing was taken away.
5. (C) If nothing can get in or out it can't change.
6. (C) Nothing is added or removed.
7. (C) Because the led is on the jar and no matter if it thick wet it will be the same.
8. (C) Because the lid is closed tightly and nothing can get in or out, that's why its the same.
9. (C) Nothing gets in, nothing gets out so the weight stays the same.
10. (C) Because whatever that is put into a jar nothing comes out and if nothing is added it should be the same.
11. (C) If nothing can get in and nothing out the contents will be the same no matter what change takes place.
12. (C) The weight of the liquid would be the same as the solid because nothing could get into it so the weight wouldn't change.
13. (C) It would weight the same because it wouldn't change because it wouldn't just change because it hardened.
14. (C) The jelly liquid will weigh the same because nothing can go in and nothing can go out therefore when it hardens it will be the same.
15. (C) It will be the same because nothing is added and nothing is taken away.
16. (C) It will way the same because no more got in nor out it will weight the same as before.
17. (C) If nothing can get in or out it must weigh the same because there is some amount of matter.
18. (A) It is going to be strall it.
19. (C) It would weigh the same because nothing could get in or out of the jar.
20. (B) It is going to be less.
21. (A) Its going to weigh more because it will be solid and kind of compressed.
22. (A) It will weigh more because it will be hardened and a jelly form will weigh more than a liquid form.
23. (A) The jelly will turn hard and weigh more. Solids are heavier than liquids.
24. (C) Because it still has the same amount of stuff in.
25. (C) All the same elements are in the jar so it is still the same weight.
26. (C) The contents in the jar will still be the same amount so the weight is the same.
27. (C) The jar should weigh the same because when it is jelly has the same material in it.
28. (C) It does not matter if it is a liquid or a solid it will still weigh the same.

Question 7: Weight conservation--object moved to edge of balance platform. Correct response = C.

Grade 11.

1. (C) It will be the same because it doesn't matter were you put it on the scale. It will weigh the same as long as its on the scale.
2. (C) It will be the same because the majority of the weight is resting on the scale.
   All the weight is still on the scale only on a smaller area or portion of it.
3. (C) The scale weighs an object the same no matter where it is situated on it.
4. (C) It would be the same because it should weigh the same no matter where you put it on the scale. It shouldn't change weight if you move it or turn it another way.
5. (C) Because no matter where it is sitting on the platform of the scale it should always weigh the same because nothing has been added or taken away.
6. (C) It will be the same because the size, shape and volume of the wood does not change, just the position of the wood on the scale changes.
7. (C) Its the same because by moving it its weight was not changed. The scale weighs an object the same no matter what part of the scale its on.
8. (C) The weight will be the same as before because the scale weighs things the same and all parts of the scale, and the block of wood didn't change.
9. (C) It doesn't gain any weight.
10. (C) The block wasn't displaced so the weight would be the same.
11. (C) It will be the same because it is the same block and does not make no difference where it is set on the scale.
12. (C) The weight will stay the same but the accuracy of the scale may be different depending on where the object is situated.
13. (B) I think it will be less because the scale does not weigh as accurately if the object is overlaping the edge of the scale.
14. (B) Because not all of the weight is placed on the scale. When it was placed in the center all of the weight was on the scale.
15. (B) Because if the weight is not in the middle, it will not be the correct measure. So it has to weigh less.
16. (B) Because if the article is not in the center it will weigh less than if it was in the center.
17. (B) Less because half the weight of the block is off the scale.
18. (B) It will be less because the weight is more accurate in the center of the balance, and the edge will not give the true weight. It will be lighter because the object isn't completely on the balance.
19. (B) It would be less as the centre of the scale gives you the accurate weight. Move the block to the side and it will weigh less.

20. (A) Because the leverage is greater, the farther out the block is.

Grade 8.

1. (C) It pushes down the same no matter where it is placed on the scale.
2. (C) I thought it was the same because the scale is balanced so it does not matter if the material is on the outside or middle of the scale.
3. (C) The piece of wood is still on the scale whether it's on the side or the middle.
4. (C) Because it has the same weight is that it is sitting more on the weight.
5. (C) I think it is the same because the wood is still on the balance.
6. (C) I think it would be the same because the weights the same.
7. (C) The weight of the same article should be the same regardless of where it is placed on the scale.
8. (C) Because it shouldn't make any difference in the weight no matter where you put it or no scale would be exact and therefore all scales would be useless.
9. (C) It is the same in size therefore it should weigh the same no matter where it is set on the balance.
10. (C) It doesn't matter where you put the piece of wood on the scale it will weigh the same.
11. (C) I think it weighed the same because when you move it around in any place the weight will be the same.
12. (C) Because when you moved the block over the weight of it was the same because the block has the same weight all through it.
13. (C) The block didn't change weight, it was just moved.
14. (C) Because the weight hasn't changed and I think the weight will to it down in any place on the scale.
15. (C) The weight will stay the same no matter where you put it.
16. (C) Nothing was added or taken off the wood.
17. (C) Well it shouldn't make any different whether it is in the middle or on the side.
18. (C) I think that it was the same because the wood is still the same volume no matter where it is.
19. (C) Because the other side doesn't weigh more so they should still weigh the same.
20. (B) It would weigh less because it is being weighed at the end because it is only half on.
21. (B) Part of the block of wood hangs over the scale and so there wouldn't be so much on the scale to give it the same weight.
22. (B) I think it would weigh less for the weight of the wood is not fully on the scale.
23. (A) I think it will be more because the weight is not distributed equally.
24. (B) I think it would be less because it is on the side and part of the weight wouldn't be weighed on the side.
25. (B) I think it is less because the block is extended over the edge and that portion will not be weighed on the scale so the weight will be less.

26. (B) I think that it would be less because the whole piece of wood was not in the middle of the scale and it wasn't on the whole scale.
27. (B) The block of wood is only half way on the scale so it will weigh less than if the whole block is on the scale.
28. (B) All the weight is in the middle and when you move the cork over a quarter of the weight is off.
29. (A) I thought it would weigh more because the scale is on a pivot and when you move it to one side it would change the pivot.

Question 8: Weight conservation--teased cotton wool ball compared with two compact balls. Correct response = B.

Grade 8.

1. (C) It will weigh less because two no matter how big weigh more than one.
2. (C) The big one weighs less.
3. (A) I chose this answer because if you make it bigger without adding to it it will not change in weight.
4. (C) The difference is because two cotton balls has the same weight.
5. (C) The bales weigh the same because the two smaller ones little air got into them, but in the third one air got in to make it weigh the same as the other two.
6. (B) The reason I chose this as you expanded it out the lighter it is going to get.
7. (B) I think it weighed less, because if we spread the two balls out that we had at first it would be more than the one spread out. When you spread it out, it was making it lighter.

Question 9: Weight conservation--cotton wool compressed in jar. Correct response = C.

Grade 9.

1. (A) It weighs more when it is punched down because the molecules bunch more together so the molecules make it heavier.

Question 10: Weight conservation--styrofoam sphere compressed. Correct response = C.

Grade 7.

1. (C) Because when you squashed it the mass is not the same.
2. (C) I think it weighed the same because it is still all there but the mass is less that's the only difference.
3. (B) Because the pair in it has been taken out of it when you flattened it out.

4. (A) When you glattened it it expanded and then it weighed more because it was packed and the round ball was not.

Question 12: Weight conservation--metal bar heated. Correct response = C.

Grade 7.

1. (A) It weighs more because the heat waves are heavy. Heat was on the bar so it was heavier.
2. (A) I think it would weigh more because the heat has gone into it and has made it heavier.
3. (A) Because when things get hot they weigh more.
4. (A) Because the heat makes it heavier.
5. (B) Because weighing less.
6. (B) Because heat sizes.
7. (B) I think it will weigh more because heat sort of shrinks its weight.
8. (B) It loses the volume.
9. (B) When the bar is heated red hot some particles fall off or break off.
10. (A) The bar would expand thus weighing more.
11. (C) Because it has the oxygen burned out of it.
12. (A) I think it would be more because the metal would be in blobs and it would be heavier.
13. (A) Because it would be hot and some of the metal would be hard and solid.
14. (A) Because when some thing is heated it expands.
15. (A) Because the molecules would spread out.
16. (A) Because the bar would swell up.
17. (A) The heat expands the aluminum molecules and makes it heavier.
18. (A) The bar when heated would expand in size which would give it more weight.

Question 13: Weight conservation--ice melted. Correct response = C.

Grade 8.

1. (C) It weighed the same, because you can never change the weight of something when you change it to a different form.
2. (C) Because there is the same volume of water in both cases so it would weigh the same.
3. (B) I think it weighed less because the ice is hard. On the lake when there is ice on it, it is heavy. When it melts it isn't heavy.
4. (A) I said it weighs more because when the ice cubes melted the water is heavier than the ice cubes. It had more volume.
5. (A) A given mass of water I think is heavier than the given mass of ice.

6. (B) Because ice cubes are solid anything solid will naturally weigh heavier than a liquid the same amount.
7. (C) I think it would weigh the less because the ice is a solid and weighs more.
8. (B) It would weigh less because it is not in cubes and is not frozen.
9. (B) I think it will weigh less because a solid will weigh more than a liquid. Therefore the ice would weigh more than the water.
10. (B) It weighed less because the ice cubes are solid and when they melt some would condense or evaporate.
11. (B) It would weigh less because when ice melts it loses some of the water and some may also evaporate.
12. (B) I thought the ice would weigh more because ice weighs less than water. After it has turned to water it should weigh more.
13. (B) It weighed more because when something is frozen the water evaporates.
14. (A) Ice is water frozen if you examine on ice closely you will see little air holes. When melted the water and bubbles mix in making the volume bigger and heavier.
15. (A) It will weigh more because when water freezes molecules of water pull together and when it melts they spread apart.
16. (A) Because the volume of the ice increased.
17. (C) I think that when the ice cubes melted it would be the same because the mass is still the same.

Question 14: Weight conservation--gasoline evaporated in can. Correct response = C.

<u>Grade 9</u>.

1. (B) The gas is evaporated into the air then it is lighter because it is mixed with the air.
2. (B) Because when the gases evaporate the weight will be less. For at first there was gases in it after there was no gases so it had to weigh less.
3. (B) If it evaporated you would not be able to use it so it must be less.
4. (B) Because the gas has evaporated and the gas that evaporated doesn't weigh anything.
5. (B) Because the liquid probably had a little weight to and then when it evaporated it was lighter because there was no more liquid.
6. (B) Once the liquid has evaporated, there will be less weight because gas is lighter than liquid.
7. (B) It will weigh less because when a gas has evaporated it doesn't weigh as much as when it's in liquid form.
8. (B) When the gasoline evaporates a gas is left and it is lighter than the liquid in the gasoline.
9. (B) Because gas vapor weighs less than liquid. I don't know why this is.

10. (B) Because when a liquid is evaporated it goes into a gas that is lighted.
11. (B) Because vapour is lighter than liquid.
12. (B) Because when we weighed the can before there was gases in it but when you weighed it after the gases has evaporated and you just weighed the can.
13. (C) Nothing can get out, nothing can get in, so must be the same.
14. (C) Nothing escapes or nothing got in so it's just logical that it will weigh the same.

Question 15: Weight conservation--paper burned in jar. Correct response = C.

Grade 9.

1. (B) The paper that was burned turned to ashes and smoke and ashes and smoke weigh less than the paper part has disappeared.
2. (B) It will only be little bit less but when the paper burns some molecules are distroyed therefore it weighs less.
3. (B) When the paper burned the flame took away some of the particles out of the paper. Therefore I think it should be less weight.
4. (C) It weighs the same because the paper hardly weighs anything so it wouldn't make much difference. It's the jar that marks the weight.
5. (C) The weight of the ashes would not change from the weight of the paper. The molecules would remain the same.
6. (C) It's going to weigh the same because the burnt paper won't make a difference in weight. It will be the same weight.
7. (B) When the paper is burned it becomes a gas and gas weighs less than a solid (paper).
8. (B) I think it weighs less because the burned paper would then be carbon and it would weigh less than paper.
9. (B) Some of the paper is gone and gives us less weight.
10. (B) I think it will weigh less because paper has burned and the ash particles weigh less than the paper as a solid.
11. (B) Because gas vapors weigh less than solid paper.
12. (B) There would be ashes and ashes weigh less than the paper.
13. (B) I think it will weigh less because of some of the paper burning and it will crumble to light, very light ashes so some of the weight would be lost and it will weigh less.
14. (B) The paper will have burned and created smoke. Since part of the paper is gone it will weigh less.
15. (B) Because it burned up.
16. (B) Because it was burnt up so it's gone.
17. (B) It weighs less because the paper (as it burns) shrivels up quite small.
18. (B) It weighs less because its used up the oxygen.
19. (B) It will weigh less because when it burned the oxygen was used up. The paper burned up a bit.
20. (B) It weighs less because it burns the paper and uses up the oxygen in the jar making it weigh less.

Question 17: Weight conservation--football pumped up. Correct response = A.

Grade 10-11.

1. (A) The air is more firmly compressed inside the football, expanding the size and increasing the volume and weight.
2. (A) When you pump more air into the ball it has more weight because it has more air. Even if the shape doesn't change there is a greater amount of air on the inside so the weight is increased.
3. (B) If you put a football on a scale when it had less air in it it would be lighter than a full one because air has weight.
4. (C) It will weigh the same because the small amount of air put in will not weigh anything.
5. (C) The oxygen is compressed in the ball weight does not affect, oxygen.
6. (C) It is the same because air doesn't weigh anything. It just has pressure so as to take up space.
7. (C) Because if the football is pumped up with air it shouldn't change because air doesn't weigh anything.
8. (C) Air does not weigh anything therefore when the ball is full of air then it will not weigh any more or any less.
9. (B) The reason the football weighs less is because it has been filled with air and no longer has the weight to weigh it down when air is within an object it rises.

Question 20: Volume conservation--displacement question--hinged wooden blocks. Correct response = C.

Grade 9.

1. (C) It will be the same because the volume of space taken is equal.
2. (C) The level would rise the same because the things are both the same shape and size.
3. (C) Because it is the same weight and size so the water will go up the same.
4. (C) It would rise the same because the volume is the same.
5. (C) Because the area which would have to be replaced by the stick in water is the same no matter the shape of the stick.
6. (C) Because the size of volume doesn't change just the shape.
7. (C) Because it's taking up the same amount of space in the water because it's the same size.
8. (C) Because when the wood was folded it was 3" long 2" wide when it was unfolded it was 6" long 1" wide they are the same size and take up the same area.
9. (C) It doesn't matter which way it goes in the volume is still the same. The wood still needs the same amount of room.
10. (C) Because the size of the wood never changed.
11. (C) Because the stick will take the same amount of volume so the water will rise the same.

12. (C) Because it takes up the same amount of space.
13. (C) The material has the same volume and occupies the same amount of space no matter which way it is.
14. (C) You are sticking just as much wood in the water.
15. (C) Volume is the same.
16. (C) It still has the same volume as it had when folded together.
17. (C) Because the volume of the stick don't change.
18. (C) Even though the shape of the block was changed. The mass of the block was not changed so that the water level would rise equally both times.
19. (C) It takes up the same volume so it would make the water rise the same.
20. (C) The same because water will go around the material no matter what position it is in.
21. (B) Because its the longer piece of wood and it would let the water rise less.
22. (B) The block has less volume therefore it will take up less space.
23. (B) It would raise less because when you open it the end comes together and it takes less room then if the two end pieces were separated.
24. (A) More because more of the stick is going in the water. And of course the water level will raise.
25. (B) Because the wood takes up more room when you open it up.
26. (A) I figure it has to raise the water up higher because there is more volume in straight stick than when it is folded up.
27. (A) Because it is longer.
28. (A) Because the wooden stick is longer therefore the water will raise higher.
29. (B) It didn't have a much volume to begin with so it wouldn't make the water level rise as much as before.
30. (A) I'll rise more because the stick has to be pushed into the water more before it becomes completely immersed thus forcing it to rise more.
31. (B) The stick is in a straight line, therefore the water can be pushed up around it easier the volume is less.

Question 22: Volume conservation--displacement question--lead foil unrolled. Correct responst = C.

<u>Grade 9B</u>.

1. (C) The weight was the same so if you immerse it, it will take up more room but the water level will rise the same amount.
2. (C) The area would be bigger but the weight would be the same.
3. (C) It's the same because the weight of lead wouldn't change so therefore it would stay the same .
4. (C) The water level rises the same cause the lead would be the same weight put apart or put together.
5. (C) The water level did not rise because it weighs the same open or closed.

6. (C) It stayed the same because the folded way it has more width than it does the unfolded way.
7. (C) The weight of it is no more it just takes up so much room.
8. (C) Well when you put the lead in the water when it is folded up is flatter and it other way is longer. But they both weigh the same.
9. (A) It rose more because when the foil was open it takes up a little more space.
10. (B) Because the mass of the object is spread over a larger area, the displaces less water.
11. (B) When it was doubled up it would make the water rise more but when it's flat no water can get in it.
12. (B) The material is heavier when it is rolled up and thus the water level will go up higher than if the material was unrolled.
13. (C) The water level will rise the same when it is in the water if it was folded up or stretched out because the weight does not change.

Question 23: Volume conservation--verbal question--clay ball split. Correct response = C.

Grade 9A.

1. (A) When it is separated it has half the thickness and the length is bigger.
2. (B) It has a less amount of room because you break it in half it has fewer grams per half, the ball is not so high.
3. (A) It has a greater volume because it is spread out to cover a larger area.
4. (C) The volume stays the same because there are the same number of molecules. Only the shape was changed.
5. (C) It is the same blob and has the same volume any way you divide it. The weight stays the same because nothing is lost.
6. (A) It doesn't displace any air when it is separated.
7. (B) You let some oxygen out then the density isn't the same.
8. (A) It takes up more room because air pressure can get around two objects, not just one object.
9. (A) Because when you split the ball more space is needed to cover it. It would decrease in weight but increase in volume.

Question 24: Volume conservation--displacement question--clay ball split. Correct response = C.

Grades 7-8.

1. (A) I think it would rise more because there is 2 objects and they would take up more space and make the water rise higher.
2. (C) They are the same weight only put in a different place so the water should rise the same.
3. (C) Because it still has the same weight when you break it in half. The water will rise the same in either way if the ball is whole or if it is in half.

4. (B) Because it is smaller so the water will not rise as high.
5. (B) I think it rises less because when it is taken apart the molecules have more room to move around so the weight is less.
6. (A) It is the same the water level because its just as much weight.
7. (C) I think it will be the same because it didn't lose any weight or gain any.
8. (A) Because before it was only one volume now it is two volumes and it will make the water go higher.
9. (C) Because it is spread and it still weighs the same and it will take up the same room.
10. (C) When that red ball is broken in half it rises more and when it is just in a whole ball it rises less because it is not broken in half.
11. (C) The water will rise the same because it is the same weight. The water will rise the same because the same volume is taken.
12. (C) Because the clay weighs the same so it the water does not rise any higher than before.
13. (C) I think the water rises the same because it still has the same weight.
14. (C) Because the ball still rises the water same because the take up less room but if you put 2 halves together they make a whole.
15. (C) I think it would just rise the same because it has the same weight and the weight of the object is what makes the water rise.
16. (A) Because these are two pieces of weight in the water.
17. (A) It will rise more because it has weight to it. And it will make the water rise.

Question 25: Volume conservation--verbal question--ball-sausage. Correct response = C.

Grade 9.

1. (C) When it is round it takes the same as if it is flat. The flat chunk looks like more but is spread out the same distance as if it would be round.
2. (C) The clay is both the same because when broken down they are still both the same and still take up the same room.
3. (A) I think the sausage takes up more room than the blob because it is longer.
4. (A) I think the sausage takes up more room because it's longer and takes up a bigger space than a ball.
5. (A) There is more exterior.

Question 26: Volume conservation--displacement question--ball-sausage. Correct response: C.

Grade 8.

1. (A) It is longer and covers more area than the ball, so the sausage

will make the water rise more.

2. (B) I think the sausage will make the water rise less. I think so because it has less weight because it is spread around more.
3. (B) I think the sausage shape will make the water rise less because it will not take up as much room as the round ball will.
4. (B) Because there was the same amount of plaster scene but when you put the plaster scene in the water, when you take it out, water is on the plaster scene so it won't be as much water in the flask.
5. (B) Because the ball would have more force when it goes in the water because it is round and bigger than the long sausage.
6. (B) When it was round it pushed the water up at a greater force, but when it was rolled out there wasn't that great of a force because it took up less space.
7. (A) It has a bigger volume and therefore it would weigh more.
8. (C) It doesn't make any difference what shape or size it is because it still has the same weight.
9. (C) When you made the clay into a long tube the mass of it gets greater or larger so naturally the water would have to go up.
10. (C) The sausage raises the water, the same as the ball, it has the same volume of weight as the ball.
11. (B) The sausage will rise less because there is not as much force pushing down on the water as there was on the ball. This would make the ball let the water rise heavier while the sausage made it rise lower.
12. (B) I think the ball would make the water level higher because it takes up more of the diameter of the glass tube.

Question 29: Volume conservation--verbal question--metal recasting. Correct response = C.

Grades 10-11.

1. (C) They are the same because if you rolled up the flat piece it could be made to look just like the rounded one. The one that looks larger is very thin whereas the other is higher and wider.
2. (C) Because when the lead was poor out it was flat and took up more room lengthwise and when it was put in the mold it took up more room in height.
3. (C) The volume is the same because though it's shape has changed the mass has not and mass determines volume.
4. (A) The volume was the same because the same amount of metal was used. The shape of the volume will be different but the amount the same.
5. (B) You heated it and metal evaporated. The volume of the flat piece of metal is therefore less.
6. (A) The metal when melted holds a bigger capacity of space than when it was not melted.
7. (B) It has less volume when it's flat because you can lay it down anywhere and it isn't in anyway.

8. (A) I think that the flat piece of metal has a greater value because it is bigger and it is flat. The other metal was smaller and it would take up more room.
9. (A) It has a bigger volume because before it was melted it was in a more condensed form and after it was melted it was in a bigger surface area.
10. (A) They weigh more, therefore they take up more amount of space.
11. (B) Because there is less capacity in volume after it was melted to a flat surface. Then when it was round. To there, it would weigh less.
12. (A) When it was small it was round and light so it took up less room, now when it has been melted it is flat so it takes up more room.
13. (A) I picked a because when it was formed the volume was all together but when it was flat there was a bigger surface so took up more room.
14. (A) I picked A for more volume because although the weight is the same, the volume or the area it takes is larger now because its shape has been altered.
15. (A) When the metal was in the first shape it was more complex and therefore had a smaller volume than the second shape which had been spread out.
16. (A) When it is in the round shape it is more compact. When it was melted it spread out over a larger area. More volume area will be needed.
17. (A) I choose A because after it was spread out and hardened it never would have fit back into the little form again.
18. (B) If you be the melt metal down it lays flat. The other piece would be harder to pack because it stands up.
19. (B) When you have melted the metal and it must have while in the liquid stage evaporated to an extent.
20. (B) I picked B it will be smaller after it has been heated because some of the molecules will be given off when it became heated.
21. (C) I think it has the same volume for the metal was at the same temperature and the molecules were the same size and distance apart in each case. They therefore occupied the same volume.

Question 32: Displacement law--large lead ball, large aluminum ball. Correct response = C.

<u>Grades 10-11</u>.

1. (B) Because of the weight of the aluminum and lead balls.
2. (C) It would rise less because much less in weight than the other ball.
3. (B) The aluminum ball would make the level rise less because of its weight upon the water. It doesn't have as much volume.
4. (B) Aluminum is lighter than lead. Lead is a heavy metal, and aluminum is lighter.
5. (B) The lead base would weigh more because lead weighs more than aluminum.
6. (B) The water level would rise less when the aluminum ball was put

in the water because aluminum is lighter.

7. (B) The aluminum ball is light so when it is put in the water it would be less than the lead ball.
8. (B) Less because it is lighter in weight.
9. (B) Lead weighs more than aluminum creating a greater force.
10. (B) Because the aluminum is lighter than the lead ball so it should take less space.
11. (B) The aluminum ball weighs less so it would displace less water.
12. (B) The aluminum ball is lighter, therefore displacing less water than the lead ball.
13. (B) Lead is heavier than aluminum, so if it has a heavier weight it causes the water to go higher.
14. (B) Because the less weight the object is the less water it will disperse.
15. (B) The aluminum ball weighs less, so if it was submerged in water, the water level would raise less.
16. (B) The aluminum ball would make the water level rise less because it is lighter and doesn't submerge in water as much.

Question 33: Displacement law--small lead ball, large aluminum ball. Correct response = A.

<u>Grades 10-11</u>.

1. (C) Lead ball is heavier than the aluminum.
2. (C) Because they are the same weight.
3. (A) I thought the aluminum ball would weigh more because its volume is bigger and weight is heavier than the other one.
4. (A) The aluminum would rise more because it has a greater density.
5. (C) I thought that the aluminum ball would make the water rise the same amount as the lead ball did because they weighed the same.
6. (C) I thought it would be the same because they looked like they were about the same weight. If they were the same weight the water would rise the same.
7. (C) The same cause the lead is smaller than the aluminum and aluminum weighs less than lead does.
8. (B) Aluminum ball will make it rise less because the weight of the ball was less than the weight of the lead ball.
9. (A) Because lead weighs more than aluminum thus when placed in water the water will rise more.
10. (C) I think the same because the aluminum ball is bigger in size and the lead ball is smaller in size so the both would weight the same.
11. (A) The aluminum ball takes up more space than the lead ball but it's mass isn't very big so it would be equal to the lead ball smaller than it.
12. (C) They would be same because lead is heavier than lead and even thought the aluminum ball was bigger so therefore it would be the same.

Question 36: Displacement law--equal sized jars containing different amounts of sand. Correct response = A.

Grades 7-8.

1. (A) I thought the water would rise more because that jar had more sand in it. Also it weighed heavier.
2. (A) The jar with more sand in would make the water rise more because there is more weight there. The volume of the sand is a lot more, too.
3. (A) Because the second one had more sand and thus more weight causing more water to rise when the second one was put in.
4. (A) I think it would rise more because there is more sand in the one jar and the more sand there is the heavier it will be.
5. (A) I thought A because the last can had more substance in than the first one. This substance would weigh more because there was more.
6. (A) I thought the jar with more sand would make the water level rise more because the volume of sand in the second jar was more than the volume of sand in the first jar.
7. (A) There is more sand in the one jar so there is more weight in this jar. The more weight the more the water rises.
8. (A) I thought this because there was more sand in the one.
9. (A) The jar with the most sand because it would weigh more.
10. (A) I thought that the jar with the most sand in it would make the water rise more because that jar is heavier.
11. (A) There was more sand in one which would increase the weight and also increase the water level.

Question 38: Displacement law--cylinder fully immersed to half depth, then full depth of container. Correct response = C.

Grade 9C.

1. (A) The weight of the object is more than the water so the farther it goes down the higher the water raises. It also has something to do with pressure.
2. (C) Because the weight of the cylinder is the same no matter how far you put it down in the water.
3. (A) If the cylinder had been placed just under the water, it would go up just slightly. Therefore, the further down the cylinder went, the higher the water level would rise.
4. (A) Because it would have more pressure if it was all the way down than if it was half way down.
5. (A) It is weight wasn't completely dispersed in the water.
6. (A) It has only displaced part of its volume in the water so you drop it all the way down it displaces all of its volume.

APPENDIX C

APPENDIX C

ATOMISTIC SCHEMES TEST FIELD TEST RESULTS

Item	Difficulty	Biserial Correlation
	Grade 7	
39	0.24	0.64
40	0.40	0.50
41	0.05	0.72
42	0.68	0.51
43	0.48	0.65
44	0.46	0.63
45	0.37	0.80
46	0.50	0.53
	Grade 9	
39	0.44	0.52
40	0.65	0.77
41	0.31	0.73
42	0.79	0.86
43	0.67	0.74
44	0.52	0.51
45	0.73	0.68
46	0.67	0.79
	Grade 7 & Grade 9	
39	0.33	0.62
40	0.51	0.67
41	0.17	0.81
42	0.73	0.66
43	0.57	0.71
44	0.49	0.55
45	0.53	0.79
46	0.57	0.67